214
6664-F
I27.60:84-18
COMPLETED
113

REC-ERC-84-18

PILOT PLANT STUDIES OF TWO PROCESSES FOR OXIDATION OF AQUEOUS SULFIDE — Paradox Valley Unit, Colorado River Basin Salinity Control Project

ORIGINAL

October 1985
Engineering and Research Center

U. S. Department of the Interior
Bureau of Reclamation

BEST COPY AVAILABLE

7-6000 (4-81)
Bureau of Reclamation

TECHNICAL REPORT STANDARD TITLE PAGE

1. REPORT NO. REC-ERC-84-18	3. RECIPIENT'S CATALOG NO.
4. TITLE AND SUBTITLE Pilot Plant Studies of Two Processes for Oxidation of Aqueous Sulfide – Paradox Valley Unit Colorado River Basin Salinity Control Project	5. REPORT DATE October 1985 6. PERFORMING ORGANIZATION CODE D-1523C
7. AUTHOR(S) W. J. Boegli and A. P. Murphy	8. PERFORMING ORGANIZATION REPORT NO. REC-ERC-84-18
9. PERFORMING ORGANIZATION NAME AND ADDRESS Bureau of Reclamation Engineering and Research Center Denver, CO 80225	10. WORK UNIT NO. 11. CONTRACT OR GRANT NO.
12. SPONSORING AGENCY NAME AND ADDRESS Same	13. TYPE OF REPORT AND PERIOD COVERED 14. SPONSORING AGENCY CODE DIBR

15. SUPPLEMENTARY NOTES

Microfiche, and/or hard copy available at E&R Center, Denver, Colorado.

Editor: RDM

16. ABSTRACT

This report presents results of field tests of two processes which show potential for use in oxidizing the sulfide contained in saturated sodium chloride ground water at Paradox Valley, Colorado; the first involving electrochemical oxidation, and the second involving aeration with catalyst.

In the first phase of the test program, aqueous sulfide, present in Paradox brine at a concentration of about 80 mg/L, was oxidized with sodium hypochlorite produced from existing brine at the site using a commercially available seawater electrolytic cell. Results showed that the process was effective in oxidizing sulfide and other reduced sulfur species present to sulfate; however, attempts at controlling the process to yield a product of elemental sulfur were not successful. The actual power consumption required for complete oxidation of all reduced species to sulfate was 6.57 kW (2.90 Wh/L) compared to a calculated requirement of 6.39 kW (2.82 Wh/L).

In a second phase of testing, statistically designed experiments were used to determine the effects of selected variables on the efficiency of a nickel-catalyzed aeration process for oxidizing sulfide in Paradox brine to elemental sulfur. Both a single-stage and a two-stage, continuous flow, cocurrent aeration system were evaluated. Results indicated more efficient oxidation using a second aeration stage with total sulfide removals exceeding 95 percent for 17 of 30 test runs compared to 90 percent for 16 of 74 runs using a single stage. These tests also showed that diffuser fouling by precipitates formed in the oxidation process may be a problem in long-term operation.

17. KEY WORDS AND DOCUMENT ANALYSIS

a. DESCRIPTORS-- sulfide oxidation/ electrochemical oxidation/ air oxidation/ diffused aeration/ aqueous sulfide/ hydrogen sulfide/ sulfide/ salinity control/ saline ground water/ sodium chloride

b. IDENTIFIERS-- Paradox Valley Unit, CO

c. COSATI Field/Group 07A COWRR: 0702, 0703 SRIM:

18. DISTRIBUTION STATEMENT Available from the National Technical Information Service, Operations Division, 5285 Port Royal Road, Springfield, Virginia 22161. (Microfiche and /or hard copy available from NTIS)	19. SECURITY CLASS (THIS REPORT) UNCLASSIFIED 20. SECURITY CLASS (THIS PAGE) UNCLASSIFIED	21. NO. OF PAGES 97 22. PRICE

BEST COPY AVAILABLE

REC-ERC-84-18

PILOT PLANT STUDIES OF TWO PROCESSES FOR OXIDATION OF AQUEOUS SULFIDE– Paradox Valley Unit, Colorado River Basin Salinity Control Project

by
W. J. Boegli
A. P. Murphy

October 1985

Applied Sciences Branch
Division of Research and Laboratory Services
Engineering and Research Center
Denver, Colorado

SI METRIC

UNITED STATES DEPARTMENT OF THE INTERIOR ★ Bureau of Reclamation

I

BEST COPY AVAILABLE

ACKNOWLEDGMENTS

The authors gratefully acknowledge the contributions made to the study by several Bureau of Reclamation employees, namely Reg Leach and Ron Pierce from the Durango Projects Office for their support in establishing the field test site and for other activities involved in the project coordination; Doug Craft and John Ellis, Chemistry Laboratory, Division of Research and Laboratory Services, for their assistance in performing water analyses at the field location; Marilyn Hudson, Structural and Architectual Branch, Division of Design, for her engineering and plant operations assistance; and to Bob Schiller, John Schaefer, Cliff Stead, Mark Olsen, Mark Wolf, Richard Swanson, and Kelly McGrath, Chemical Engineering Laboratory, Division of Research and Laboratory Services, for their assistance in the construction and operation of the pilot plant and for various other tasks performed in support of the project.

As the Nation's principal conservation agency, the Department of the Interior has responsibility for most of our nationally owned public lands and natural resources. This includes fostering the wisest use of our land and water resources, protecting our fish and wildlife, preserving the environmental and cultural values of our national parks and historical places, and providing for the enjoyment of life through outdoor recreation. The Department assesses our energy and mineral resources and works to assure that their development is in the best interests of all our people. The Department also has a major responsibility for American Indian reservation communities and for people who live in Island Territories under U.S. Administration.

The research covered by this report was funded by the Bureau's Upper Colorado Regional Office under Title II of the Colorado River Basin Salinity Control Act.

The information contained in this report regarding commercial products or firms may not be used for advertising or promotional purposes and is not to be construed as an endorsement of any product or firm by the Bureau of Reclamation.

BEST COPY AVAILABLE

CONTENTS

	Page
Glossary of chemical symbols, acronyms, and abbreviations	v
Introduction	1
Influent properties	1
Phase I testing: electrochemical oxidation	2
Plant description	2
Process chemistry	2
Test procedures	5
Results and discussion	5
Influent variations	5
Phases I-1 and I-1a	6
Phase I-2	9
Phase I-3	9
Conclusions	12
Phase II testing: nickel-catalyzed air oxidation	13
Process chemistry and variable selection	13
Previous investigations	16
Phase II – single-stage aeration	17
Plant description	17
Test procedures	19
Analytical methods	19
Results and discussion	21
Phase IIa – two-stage aeration	34
Plant description	34
Test procedures	36
Results and discussion	37
Postaeration solids removal	44
Conclusions	45
Recommendations for further investigation	46
Bibliography	46
Appendix A – Phase II test data	47
Appendix B – Phase IIa test data	72

TABLES

Table		
1	Major and selected trace metal ion concentrations in Paradox brine	1
2	Phase I test program	5
3	Phase II test variables and independent variable levels	22
4	Phase II experimental design	23
5	Verification data for modified titrimetric (iodine) method for total sulfide in Paradox brine	25
6	Summary of phase II regression results	27
7	Phase IIa test variables and independent variable levels	37
8	Phase IIa experimental design	38
9	Summary of phase IIa regression results	39

BEST COPY AVAILABLE

CONTENTS – Continued

FIGURES

Figure		Page
1	Flow diagrams for electrochemical oxidation test unit	3
2	Electrochemical oxidation test unit	4
3	Closeup view of figure 2 showing voltage rectifier and electrolytic cells	4
4	Variation of influent sulfur species concentration versus time	6
5	Phase I-1 data	7
6	Phase I-1a data	8
7	Sulfur suspension in plant effluent during phase I-1a testing	9
8	Phase I-2 data	10
9	Cell voltage versus time for phase I-3	11
10	Cell pressure versus time for phase I-3	12
11	Cell electrodes subsequent to phase I-3 testing	13
12	View showing sodium chloride and sulfur deposits at inlet of cell 1	13
13	Cell cover plates subsequent to phase I-3 testing showing discoloration at outlet of cell 2	14
14	Sulfide/thiosulfate concentration versus sampling time	15
15	Residual chlorine versus sampling time	15
16	Catalyst of sulfide oxidation by nickel ion at pH 8.65	16
17	Flow diagram for phase II aeration unit	18
18	Influent flow regulation equipment and Fortin barometer	19
19	Chromalox in-line brine heater and associated solid-state controller	19
20	Catalyst batch tank and mixer	20
21	Two of the three insulated aeration columns used in phase II testing	20
22	Compressed air supply and Hastings linear mass-flowmeter	21
23	Gas-liquid separator and effluent sampling points	21
24	Effluent H_2S gas sampling apparatus	26
25	Comparison of data from two analytical methods for measurement of effluent H_2S gas	26
26	Phase II effluent brine data (49.5-μm mean diffuser pore diameter)	28
27	Phase II effluent brine data (8.5-μm mean diffuser pore diameter)	29
28	Phase II effluent gas data (49.5-μm mean diffuser pore diameter)	30
29	Phase II effluent gas data (8.5-μm mean diffuser pore diameter)	31
30	Variation in orifice Reynolds number and total bubble surface area with diffuser pore size and air mass-flow rate	32
31	Typical unfiltered effluent brine sample	33
32	Diffuser plate assembly subsequent to phase II testing	34
33	Flow diagrams for phase II and IIa aeration units	35
34	Two-stage, gas recycle, aeration system for phase IIa	36
35	First-stage aeration column and liquid-level controller	36
36	Phase IIa interstage brine data	40
37	Phase IIa interstage gas data	41
38	Phase IIa effluent brine data	42
39	Phase IIa effluent gas data	43
40	Phases II and IIa effluent brine data comparison	44
41	Phases II and IIa effluent gas data comparison	44
42	Effluent turbidity as a function of $FeCl_3$ concentration for a 15-minute settling time	45
43	Centrifuge test results on aerated brine samples	45

BEST COPY AVAILABLE

GLOSSARY OF CHEMICAL SYMBOLS, ACRONYMS, AND ABBREVIATIONS

CHEMICAL SYMBOLS/FORMULAS

$Al_2(SO_4)_3 \cdot 14H_2O$	aluminum sulfate tetradecyl hydrate (alum)
Ca^{+2}	calcium ion
$CaCO_3$	calcium carbonate
$Ca(OH)_2$	calcium hydroxide (lime)
$CaSO_4$	calcium sulfate
Cl_2	chlorine gas
Cl^-	chloride ion
ClO_3^-	chlorate
Co^{+2}	cobalt ion
CO_2	carbon dioxide
Cu^{+2}	copper ion
Fe^{+2}	ferrous ion
Fe^{+3}	ferric ion
$FeCl_3$	ferric chloride
$Fe(OH)_3$	ferric hydroxide
H^+	hydrogen ion
H_2	hydrogen gas
HCl	hydrochloric acid
HCO_3^-	bicarbonate ion
HO_2^-	hydroperoxide ion
HOCl	hydrochlorous acid
H_2S	hydrogen sulfide
HS^-	bisulfide ion
I_2	iodine
K^+	potassium ion
KCl	potassium chloride
M^{+2}	divalent metal ion
Mg^{+2}	magnesium ion
$Mg(OH)_2$	magnesium hydroxide
MHS^+	metal sulfide complex
Mn^{+2}	manganese ion
Na^+	sodium ion
NaCl	sodium chloride
NaOCl	sodium hypochlorite
Na_2S	sodium sulfide
Ni^{+2}	nickel ion
NiS	nickel sulfide
$NiSO_4$	nickel sulfate
$NiSO_4 \cdot 6H_2O$	nickel sulfate hexahydrate
O_2	oxygen
OCl^-	hypochlorite ion
OH^-	hydroxide ion
S^0	elemental sulfur
S^{-2}	sulfide ion
SiO_2	silicon dioxide (silica)
SO_3^{-2}	sulfite ion
SO_4^{-2}	sulfate ion
$S_2O_3^{-2}$	thiosulfate
ΣS^{-2}	total sulfide concentration (summation of H_2S, HS^-, and acid soluble metal sulfides)

BEST COPY AVAILABLE

ACRONYMS/ABBREVIATIONS

A	ampere
AOV	analysis of variance
Atm	atmosphere
°C	degree Celcius
CRWQIP	Colorado River Water Quality Improvement Program
F_c	centrifugal force
g/L	gram per liter
g/mL	gram per milliliter
h	hour
ICP	inductively coupled plasma
kg/d	kilogram per day
kPa	kilopascal
kW	kilowatt
kWh/kg	kilowatt hour per kilogram
L	liter
L/min	liter per minute
L/s	liter per second
m	meter
mg/L	milligram per liter
mg/m^3	milligram per cubic meter
min	minute
mL/min	milliliter per minute
mm	millimeter
MWh/d	megawatt hour per day
n	sample population
NTU	nephelometric turbidity unit
P_{O_2}	partial pressure of oxygen
Pa·s	pascal second
PVC	polyvinyl chloride
$S_{\bar{x}}$	standard deviation
sL	standard liter (gas flow adjusted to standard temperature and pressure)
sL/min	standard liter per minute
TDS	total dissolved solids
V	volts
Wh/L	watt hour per liter
W/m^2	watt per square meter
$\bar{x}$	mean
X_i	independent variable
Y_i	dependent variable
µm	micrometer

BEST COPY AVAILABLE

INTRODUCTION

The work described in this report was performed in support of the Paradox Valley Salinity Control Investigation, CRWQIP (Colorado River Water Quality Improvement Program), authorized under Title II of the "Colorado River Basin Salinity Control Act" of June 24, 1974 (Public Law 93-320).

Paradox Valley, a collapsed salt anticline, is a northwest-southeast trending valley 3 to 5 miles (4.8 to 8 km) wide located in southwestern Colorado. The valley is traversed near its midpoint by the Dolores River. As it crosses the valley, the river channel interfaces with a concentrated brine source containing about 260 000 mg/L of TDS (total dissolved solids), which contributes an annual salt load to the river of about 185 000 metric tons. The salinity of the river, measured during extreme low flows, has been as high as 166 000 mg/L at the outlet of the valley. In addition to its high salt content, the Paradox brine contains substantial concentrations of sulfide, about 75 to 100 mg/L depending on the test well sampled, which result primarily from the bacterial reduction of sulfate under anaerobic conditions. Sulfide-bearing waters are corrosive in nature and toxic at higher concentrations.

The planned salinity control measure for Paradox Valley is to install a series of wells on both sides of the river at the brine source to lower the freshwater-brine interface and thus, by pumping, greatly reduce the natural brine inflow to the river. It has been estimated that 160 000 metric tons of salt can be diverted in this manner by pumping at a rate of about 57 L/s (2 ft^3/s). At the time the testing outlined in this report was completed, it was planned that the brine would be collected and pumped to a terminal evaporation pond in Dry Creek Basin, located about 20 miles (32 km) southeast of the brine well field area.[1] To achieve this method of disposal, it would be necessary to remove sulfide from the brine to prevent the serious corrosion of the pumping facilities and the release of sulfide and extremely odorous hydrogen sulfide gas at the disposal pond.

This report presents the results of pilot plant studies of two processes which show potential for use in the removal of sulfide in Paradox brine, the first involving electrochemical oxidation (test phase I), and the second, a nickel-catalyzed aeration process (test phase II). The latter process was used successfully by the Pacific Gas and Electric Co. at their Geyser facility in California for the oxidation of sulfide in recirculating powerplant cooling water.

[1] Subsequent to the completion of this testing, the planned method of brine disposal was changed to deep well injection based on a reassessment of technical, economic, and environmental considerations. Evaporation pond disposal studies, to include any additional investigation of the sulfide removal processes described herein, have been suspended pending the results of deep well injection tests.

INFLUENT PROPERTIES

Paradox brine is saturated in NaCl (sodium chloride) and has a density and viscosity of 1.165 g/cm^3 and 0.0019 Pa·S, respectively, at an average wellhead temperature of 15.7 °C. The concentrations of major and selected trace metal ions, measured in samples taken from well PH-6W, are presented in table 1. The metal ions shown are those known to exert a significant catalytic effect in the air oxidation of sulfide, and are listed in order of effectiveness. Influent pH and total sulfide concentration, ΣS^{-2} (summation of H_2S, HS^-, and acid soluble metal sulfides), averaged 6.3 pH units and 77.9 mg/L during phase I, and 7.5 pH units and 81.7 mg/L during phase II, respectively. For this pH range, the predominant sulfide species in an aqueous system are H_2S (hydrogen sulfide) and HS^- (bisulfide), with the latter being most prevalent between pH 7 and 11.

Influent for both test phases was extracted from well PH-6W at a depth of about 18 m. Due to the relative positions of the pilot plant and wellhead, it was necessary to transfer influent, under pressure, through a buried 50-mm pipe for about 100 m. As

Table 1. — Major and selected trace metal ion concentrations in Paradox brine.[1]

	Detection limit, mg/L	Concentration, mg/L
Calcium, Ca^{+2}		1 600
Magnesium, Mg^{+2}		3 420
Sodium, Na^+		89 100
Potassium, K^+		4 880
Chloride, Cl^-		141 000
Sulfate, SO_4^{-2}		5 730
Bicarbonate, HCO_3^-		260
TDS		246 000
Nickel, Ni^{+2}	0.02	ND[2]
Cobalt, Co^{+2}	.009	ND
Manganese, Mn^{+2}	.002	0.51
Copper, Cu^{+2}	.004	ND
Iron, Fe^{+2}	.004	ND

[1] Metal ions were measured using an inductive coupled plasma emission spectrograph to avoid background interference due to the salt matrix.
[2] ND indicates not detected.

BEST COPY AVAILABLE

a result, brine temperature at the plant intake varied from 11.7 to 15.8 °C during phase I and from 10.3 to 18.6 °C during phase II, depending on the ambient air temperature and brine flow rate.

PHASE I TESTING: ELECTROCHEMICAL OXIDATION

During phase I, an electrochemical process was field tested to determine its effectiveness in oxidizing aqueous sulfide in Paradox brine. Overall test objectives were to evaluate the ability of an electrolytic cell (Sanilec seawater system) to produce NaOCl (sodium hypochlorite) using Paradox brine as cell feed, and subsequently, to assess the effectiveness of the resultant NaOCl solution in oxidizing ΣS^{-2} to either S^0 (elemental sulfur) or SO_4^{-2} (sulfate ion). This section of the report presents a detailed description of the pilot plant equipment used, process chemistry, test procedures, results, and conclusions.

Plant Description

The Sanilec electrolytic cell used in this test phase is manufactured by the Electrode Corp., a division of Diamond Shamrock. The particular system tested uses two nondiaphragm seawater cells in series, which produce a maximum of about 68 kg/d of Cl_2 in the form of NaOCl, when operating with seawater as feed. The concentration of the NaOCl solution, expressed as available Cl_2 (chlorine), is normally about 0.1 percent. The manufacturer's projected power consumption for feed conditions found at Paradox range between 3.31 and 4.08 kWh/kg of Cl_2 for production rates from 22.7 to 68.0 kg/d.

The cell is designed to operate at a fixed flow rate of 1.26 L/s (20 gal/min); thus, for a particular water composition, the only controllable independent variable relating to the cell operation is the applied current. Based on this fixed flow rate, it was estimated that 76.2 kg/d of Cl_2 would be required to oxidize 77.9 mg/L of ΣS^{-2} (mean concentration for well PH-6W) to SO_4^{-2}, or 84.3 kg/d of Cl_2 to oxidize all reduced sulfur species present. Since these Cl_2 production levels exceed the design capacity of the Sanilec system, it was necessary, during a portion of the testing, to recycle treated plant effluent to dilute the incoming brine ΣS^{-2} concentration.

Major items of equipment and sampling points included in the pilot plant are shown on figure 1. The system was configured to operate in two separate flow regimes accommodating different test phase requirements, which will be described later. Figure 2 shows the plant as it was set up in the field. The rectifier and two electrolytic cells can be seen in the background on this figure and on the closeup view on figure 3. The equipment shown in the foreground of figure 2, at ground level, includes the sump and in-line filter assembly to the left and reaction tank and associated mixer to the right. The gas separator used to vent H_2 (hydrogen gas) from the process can be seen immediately above and behind the reaction tank.

Process Chemistry

The electrolysis of NaCl at inert electrodes yields chlorine gas (Cl_2) at the anode and H_2 at the cathode according to the following reactions:

Reduction at cathode: $H_2O + e^- \longrightarrow 0.5H_2 + OH^-$

Oxidation at anode: $Cl^- \longrightarrow 0.5Cl_2 + e^-$

In a membraneless cell, Cl_2 combines with hydroxyl ions (OH^-) to produce hypochlorous acid (HOCl) and hypochlorite ion (OCl^-) according to the following equilibriums:

$$Cl_2 + OH^- \rightleftharpoons HOCl + Cl^-$$

$$HOCl \rightleftharpoons OCl^- + H^+$$

At a pH > 4, the first equilibrium displaces greatly to the right and very little Cl_2 exists in solution. The relative amounts of OCl^- and HOCl in solution is a function primarily of pH, temperature, and total ionic strength.

There are several secondary reactions which, in effect, reduce the conversion of Cl^- to HOCl. These reactions include:

- Reaction between OCl^- and HOCl to chlorate (ClO_3^-) and Cl^-:

$$OCl^- + 2HOCl \longrightarrow ClO_3^- + 2H^+ + 2Cl^-$$

- Decomposition of HOCl:

$$2HOCl \longrightarrow 2HCl + O_2$$

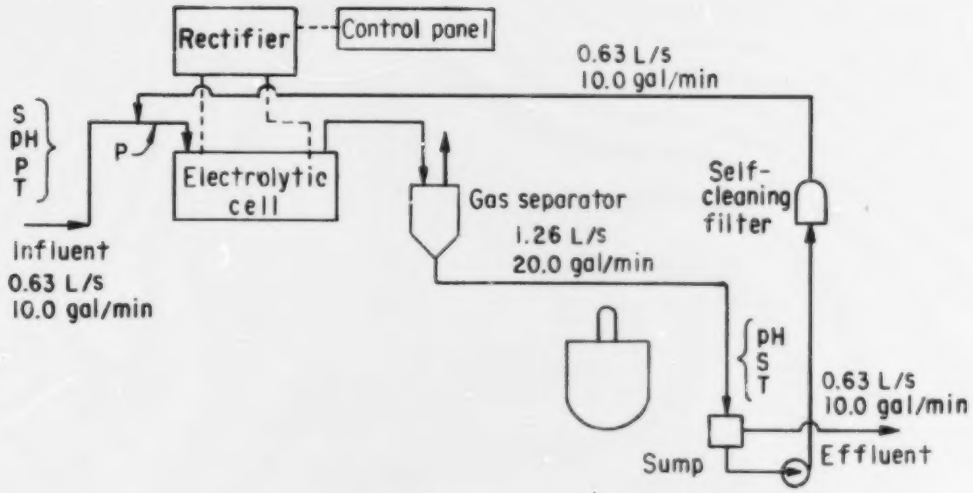
- Cathodic reduction of HOCl according to the reaction:

$$HOCl + 2H \longrightarrow H_2O + H^+ + Cl^-$$

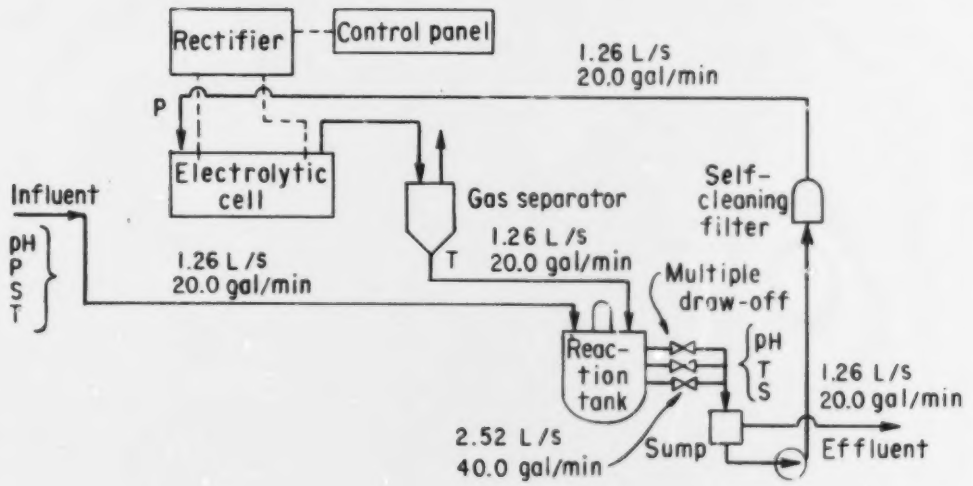
These reactions are minimized by maintaining the concentration of HOCl in solution at a low level, by operating at temperatures below 25 °C, and by proper cell design.

The oxidation of sulfide to SO_4^{-2} and S^0, at influent pH values considered herein, will then proceed theoretically according to the following overall reactions:

BEST COPY AVAILABLE



PHASES I-1 AND I-3



PHASE I-2

Figure 1. – Flow diagrams for electrochemical oxidation test unit. Transducers are shown as pH, P (pressure), T (temperature), and S (sampling points).

BEST COPY AVAILABLE

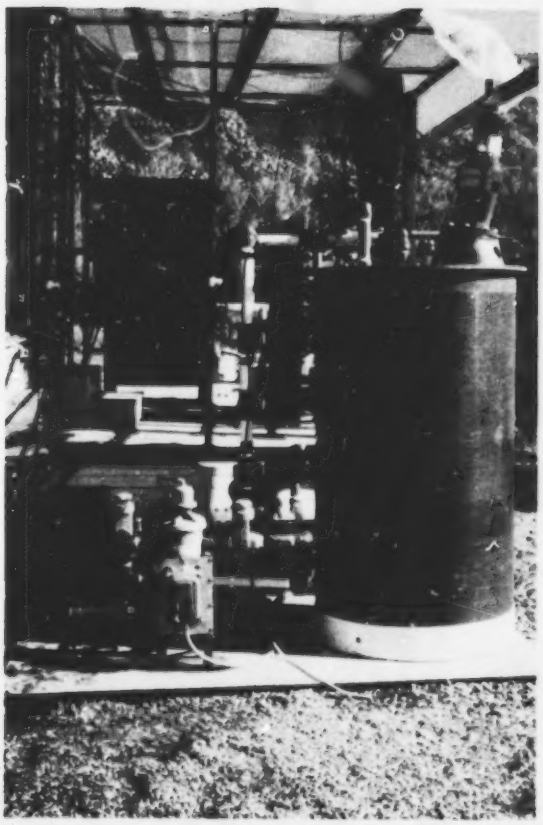


Figure 2. – Electrochemical oxidation test unit. P801-D-80927.

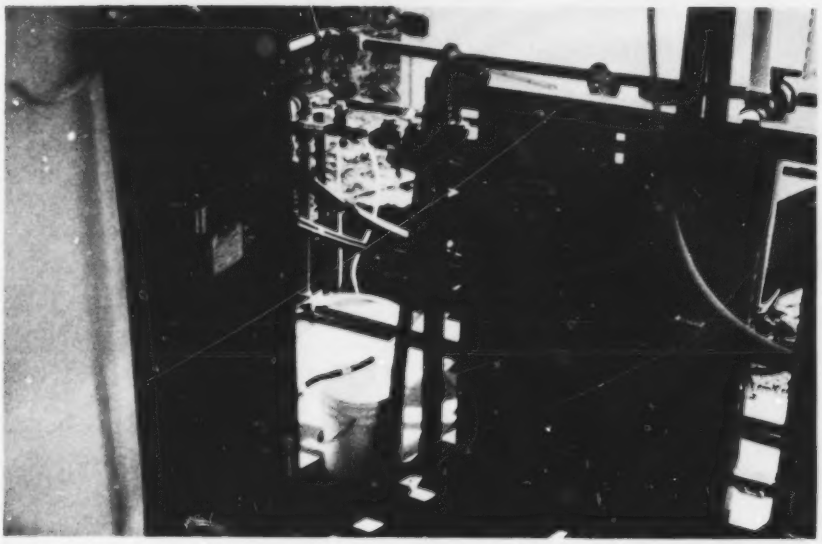


Figure 3. – Closeup view of figure 2 showing voltage rectifier and electrolytic cells. P801-D-80928.

BEST COPY AVAILABLE

$$4OCl^- + HS^- \longrightarrow SO_4^{-2} + 4Cl^- + H^+$$

$$OCl^- + HS^- + 2H^+ \longrightarrow S^o + H_2O + Cl^- + H^+$$

Test Procedures

Testing was divided into two phases (further division of phase I) as follows:

(1) Electrochemical oxidation to sulfate ion (SO_4^{-2}), and

(2) Electrochemical oxidation to elemental sulfur (S^o).

In the first test phase (I-1), influent brine was fed directly to an electrolytic cell where both the generation of OCl^- and the oxidation of sulfide to SO_4^{-2} took place. Specific parameters monitored during this operation included completeness of oxidation as a function of applied cell current (as evidenced by changes in concentration of selected sulfur species), pH and temperature changes, and scaling or fouling tendencies at the electrodes.

In the second test phase (I-2), an attempt was made to uniformly oxidize influent sulfide to S^o in an external reactor. Influent brine was fed directly into a sealed reaction tank where it was mixed with a NaOCl stream from the electrolytic cell. Feed to the cell was diverted from the treated plant effluent. Parameters monitored were the same as those noted in the previous paragraph. Flow paths and rates used in each phase are shown on figure 1.

The completed test program consisted of 17 experimental runs, as shown in table 2. Runs 1-12 and 13-16 were short-term tests designed to establish operating curves for phases I-1 and I-2, respectively. Each set of curves was established by operating the system at incremental current settings within an experimental region. The region was sufficiently broad to establish data points well above and below the predicted current setting for stoichiometric NaOCl production. At each setting, samples of plant feed and effluent were collected and analyzed for ΣS^{-2}, S^o, $S_2O_3^{-2}$ (thiosulfate), and SO_3^{-2} (sulfite). The curves then indicated the decline in ΣS^{-2} and net change in the more oxidized states of sulfur as a function of the current setting. These sulfur species, as well as SO_4^{-2} (S^{+6}) which was not measured during testing, were selected as being representative of the oxidation states prevailing within the system.

In phase I-2, where the oxidation took place in an external reactor, data points were established for three separate reactor liquid residence times (2.58, 3.80, and 5.23 minutes) at each current setting.

Phase I-3 (run 17) involved extended operations at phase I-1 conditions. The current setting of 900 amperes was selected based on the results of runs 1 through 12. Specific items of interest during this run were fouling tendencies at the electrodes and variations in cell pressure and voltage with time.

Table 2. – Phase I test program.

Run No.	Phase	Rectifier current setting, amperes	Reactor liquid residence, minutes[1]	Duration, hours
1	I-1	625	–	–
2	I-1	750	–	–
3	I-1	875	–	–
4	I-1	1000	–	–
5	I-1	1125	–	–
6	I-1	1250	–	–
7	I-1a	625	–	–
8	I-1a	750	–	–
9	I-1a	875	–	–
10	I-1a	1000	–	–
11	I-1a	1125	–	–
12	I-1a	1250	–	–
13	I-2	500	2.58	–
			3.80	–
			5.23	–
14	I-2	750	2.58	–
			3.80	–
			5.23	–
15	I-2	1000	2.58	–
			3.80	–
			5.23	–
16	I-2	1250	2.58	–
			3.80	–
			5.23	–
17	I-3	900	–	144

[1] Calculated based on a flow rate of 2.52 L/s.

Results and Discussion

Influent Variations. – Figure 4 shows the variation in influent concentration, measured over a period of 20 days, for each of the representative sulfur species (oxidation states). The mean ($\bar{x}$), standard deviation ($S_{\bar{x}}$), and number of samples (n) are presented for each data set.

Initially, the influent ΣS^{-2} levels fluctuated between 40 and 80 mg/L (not shown on fig. 4) causing some concern regarding the analytical procedure. However, it was finally concluded that the influent brine was unstable; i.e., brine had not reached steady-state conditions during first few hours of pumping. After a period of continuous operation, the ΣS^{-2} measure-

BEST COPY AVAILABLE

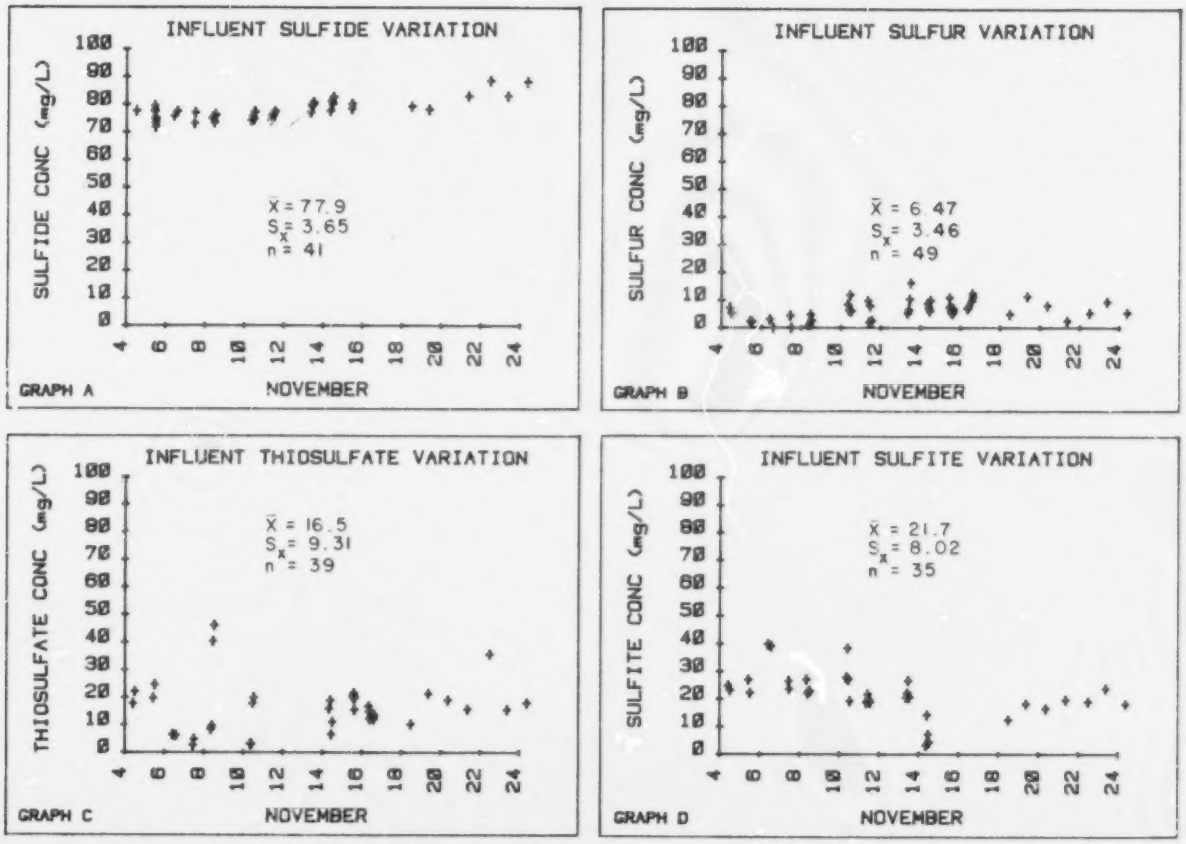


Figure 4. – Variation of influent sulfur species concentration versus time.

ments stabilized except for a gradual increase, with time, of 5 to 7 mg/L over the 3-week period of operation.

Influent $S_2O_3^{-2}$ concentrations measured during the first week of testing were extremely erratic. Upon review of the sampling and laboratory techniques, a correlation was found to exist between $S_2O_3^{-2}$ levels, the time between sampling and analysis, and the extent of air exposure. Initially, both ΣS^{-2} and $S_2O_3^{-2}$ samples had been extracted from the same sample bottle, the former being taken first. The $S_2O_3^{-2}$, a reducing agent, was reacting with trapped O_2 in the bottle, thus decreasing in concentration. Subsequently, separate sample bottles were used for each species to eliminate this problem.

Five successive influent SO_4^{-2} analyses were performed, each indicating a concentration greater than 6000 mg/L of SO_4^{-2} with a relative standard deviation of 1.9 percent. From this result, it was concluded that, with the analytical method used, it would be impossible to detect changes in concentration of about 20 to 40 mg/L, which would be necessary to detect oxidation from the SO_4^{-2} concentration change. No further SO_4^{-2} analyses were attempted.

Phase I-1 and I-1a. – Figures 5 and 6 present data for phases I-1 and I-1a, respectively. Cell current values used represent practically the entire operating range of the Sanilec rectifier. Upon completion of the phase I-1 runs, it became evident that a downward extension of each graph would be required to show definitive concentration breakpoints (cell currents below which positive effluent values begin appearing). This was accomplished in phase I-1a by eliminating the recycle and increasing the influent rate to 1.26 L/s, effectively doubling the ratio between influent ΣS^{-2} concentration and cell current over the amperage range tested. Graphs B and D (fig. 6) show the breakpoints for ΣS^{-2} and $S_2O_3^{-2}$, respectively.

Graphs A (figs. 5 and 6) present effluent pH for the full range of current settings in both phases I-1 and I-1a. On both curves, and at about the same current versus influent ΣS^{-2} concentration ratio, there is a dip

BEST COPY AVAILABLE

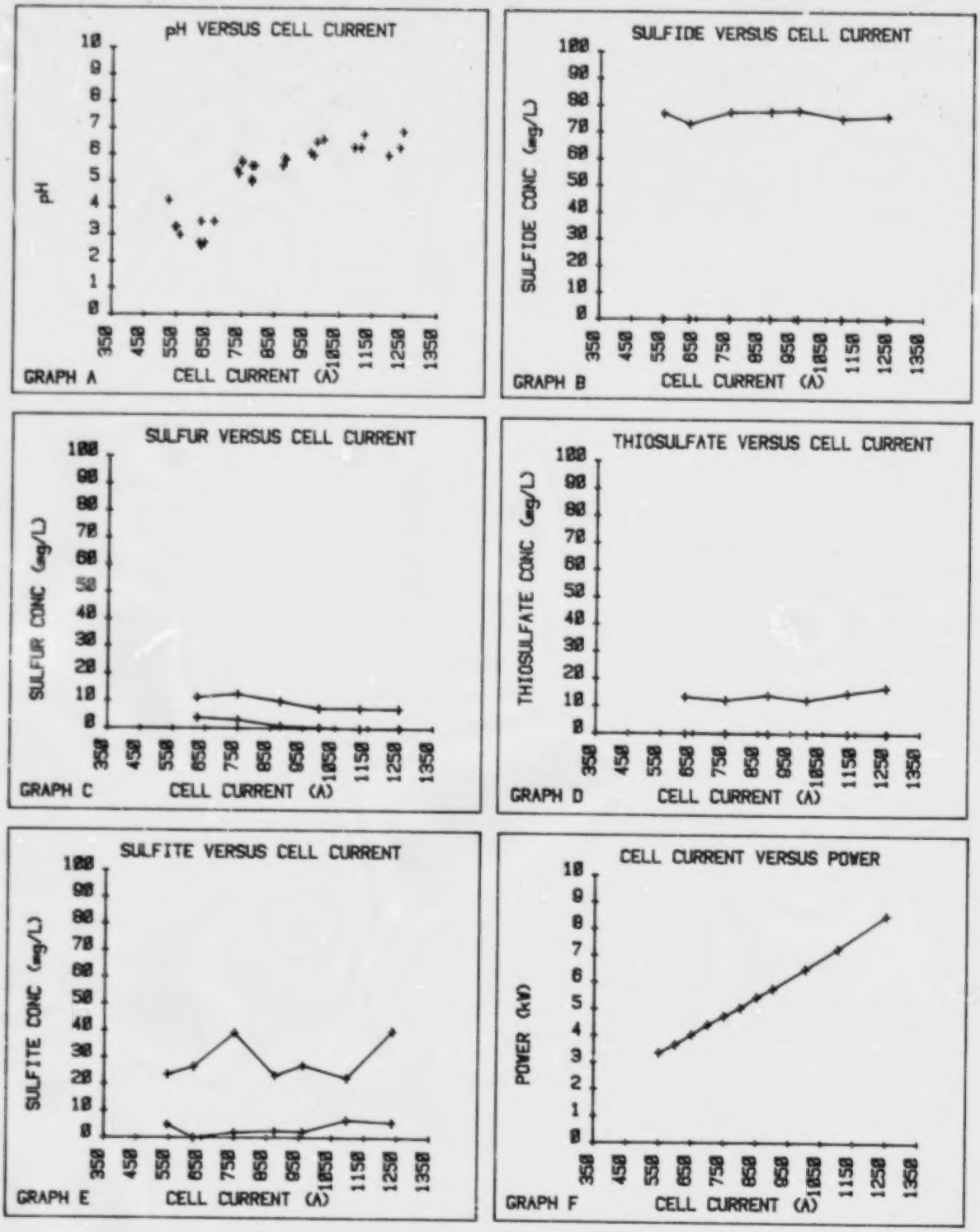


Figure 5. – Phase I-1 data. Upper plot in graphs B through E indicate influent values.

BEST COPY AVAILABLE

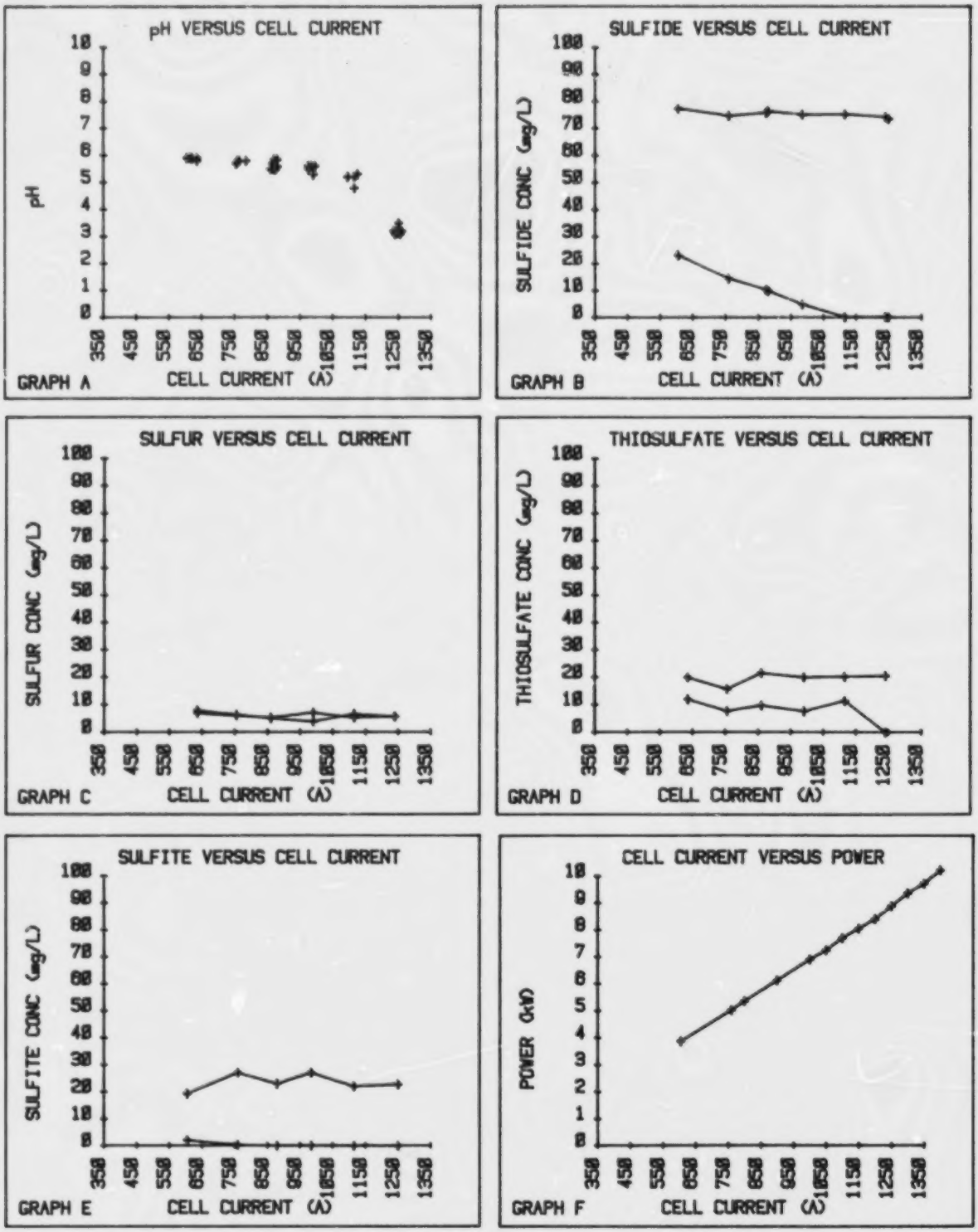


Figure 6. – Phase I-1a data. Upper plot in graphs B, D, and E indicate influent values.

BEST COPY AVAILABLE

in effluent pH to about 2.5. No correlation to other physical or chemical phenomena has been found to explain this dip in pH.

Graphs F (figs. 5 and 6) show the variation in power consumption, as computed from the product of cell current and voltage, versus current setting for each phase.

The results of the phase I-1 operations (fig. 5) show that complete oxidation of sulfide, as well as other reduced sulfur species, can be achieved. All species disappear, except for a small concentration of SO_3^{-2}, when operating at a cell current of about 900 A; however, operation anywhere within the phase I-1 experimental range would appear to yield satisfactory results.

Throughout the phase I-1a operations, and at the lower current settings in phase I-1, a distinct yellow color developed in the plant effluent. Between 850 and 1250 A in phase I-1a, this coloration evolved to a yellow, spongelike floating residue (fig. 7). This material was later identified by X-ray diffraction analysis as consisting predominantly of elemental sulfur (S^o) and NaCl, with a minor concentration of $Mg(OH)_2$. The introduction of this solid phase made it difficult to obtain representative samples for effluent S^o analysis. The precipitation of S^o throughout the plant, combined with the occasional dislodgement of particles, led to unavoidable errors in S^o measurements. At current settings of 750 A and below for phase I-1a, the plant effluent exuded a strong H_2S odor.

Phase I-2. – Figure 8 presents test results for phase I-2. Unconnected data points on graphs B through E represent influent values, while the curves (connected data points) indicate effluent levels at each of three reactor liquid residence times. The $S_2O_3^{-2}$ concentration data for two residence times, 2.58 and 3.80 minutes, were discarded due to errors in sampling.

As stated previously, the object of this phase of testing was to attempt uniform oxidation of influent ΣS^{-2} to S^o, in an external reactor, without significantly affecting the remaining sulfur species, (fig. 1). Assuming an average influent ΣS^{-2} concentration of 77.9 mg/L, an influent rate of 1.26 L/s, and a power consumption of 3.22 kWh/kg of Cl_2 (based on the manufacturer's projections), a rectifier power output of 2.38 kW would theoretically be needed. The actual power output required to oxidize ΣS^{-2} to extinction was 6.4 kW (fig. 8, graphs B and F), or about 2.7 times the theoretical case. It can be seen from graphs C through E on figure 8 that other species were, in fact, being oxidized. All species appeared to oxidize toward SO_4^{-2} regardless of the flow regime. It also appeared that reactor residence time had little effect on effluent concentrations.

Phase I-3. – Considering the data presented on figures 5 and 6, it was determined that the best performance, based on disappearance of all reduced sulfur species, was achieved at phase I-1 conditions, with an operating current of 900 A. These conditions were selected for the extended run (phase I-3). Cell pressure and voltage data for this phase are

Figure 7. – Sulfur suspension in plant effluent during phase I-1a testing. P801-D-80929.

BEST COPY AVAILABLE

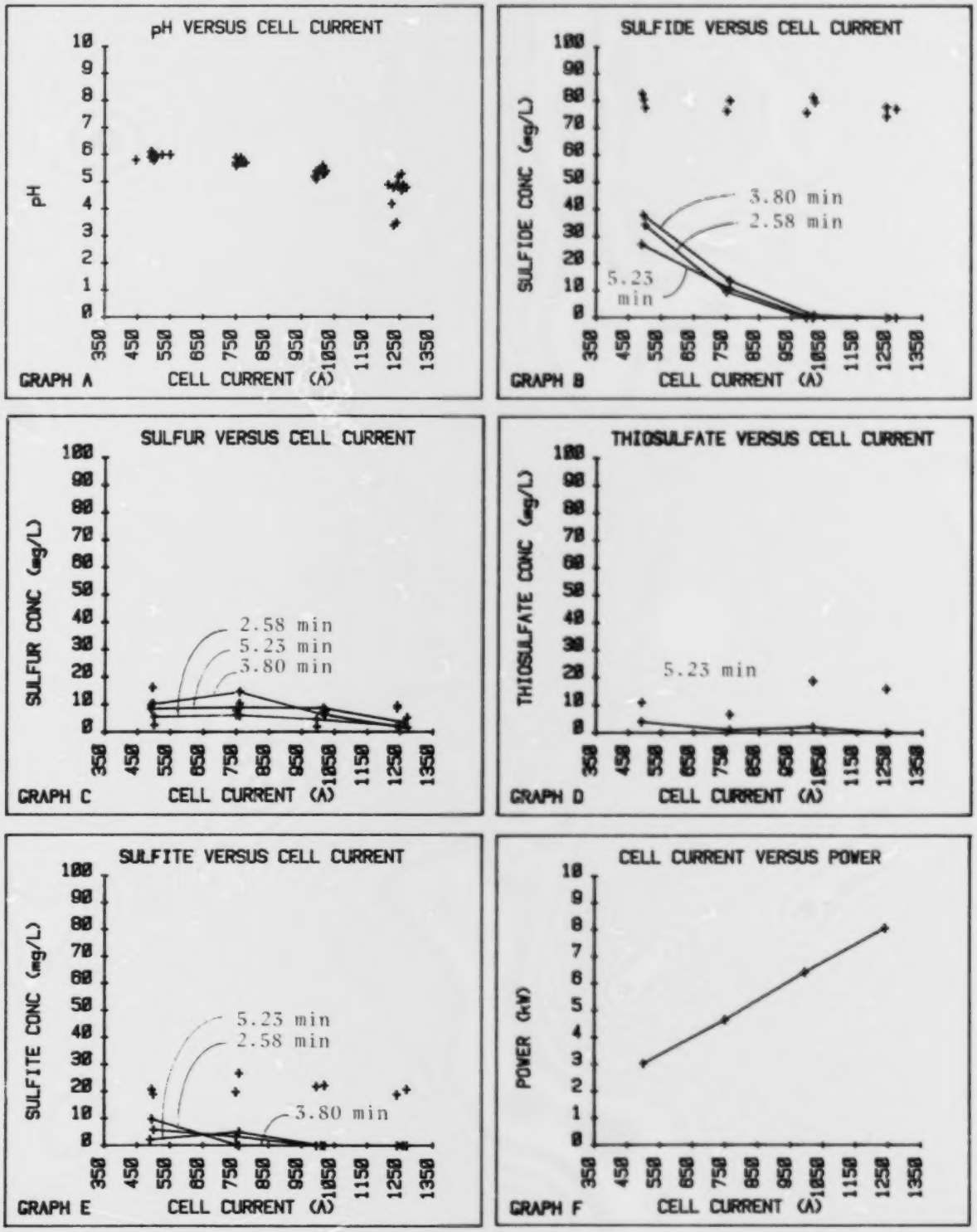


Figure 8. – Phase I-2 data. Unconnected data points in graphs B through E represent influent values.

BEST COPY AVAILABLE

shown on figures 9 and 10, respectively. Cell voltage readings remained fairly constant at 7.3 V during the last 95 hours of the run, yielding an average power consumption of 6.57 kW (2.90 Wh/L), which would be equivalent to 14.3 MWh/d for a continuous brine flow of 57 L/s. This compares to a predicted power requirement of 5.21 kW (2.30 Wh/L) for oxidation of 77.9 mg/L of ΣS^{-2} to SO_4^{-2}, and an estimated requirement of 6.39 kW (2.82 Wh/L) for oxidation of all measured sulfur species to SO_4^{-2}. This estimate was based on the mean concentration of each species as shown on figure 4. Cell pressure increased steadily throughout the 144-hour test period from 29.0 to 46.6 kPa.

Upon completion of the extended run and prior to acid cleaning, the cell cover plates were removed for a visual inspection of the electrodes (figs. 11 and 12). Salt deposits were found enmeshed within the grid of the dimensionally stable anodes at the inlet of both cells, and a whitish-yellow, paste-like substance was found adhering to all wetted parts near the inlet along the rank of terminal bolts of cell 1 and, to a lesser degree, in cell 2. An X-ray diffraction analysis of this material indicated the major constituents to be halite (NaCl) and sulfur with no other significant components detected. In addition, a rust-brown discoloration developed in and around the outlet and along the positive terminal strip of cell 2. This can be seen on figure 11 and on the cover plate of cell 2 on figure 13. This material was found to consist predominantly of iron oxide, with moderate concentrations of calcite ($CaCO_3$) and NaCl. Minor constituents detected included gypsum ($CaSO_4 \cdot 2H_2O$), quartz (SiO_2), and potassium chloride (KCl). Acid cleaning of the cells with 10 percent HCl (hydrochloric acid) effectively removed the precipitated salts, but left much of the adhering sulfur.

Another run was planned, subsequent to acid cleaning, to determine the degree of recovery to prephase I-3 conditions. However, before the run could be accomplished, the main line supplying power to the test site dropped a phase, causing considerable damage to the influent pump. At that point, testing had to be terminated.

During phase I-3 testing, the frequency of sampling was considerably reduced from that of earlier runs. This resulted in faster turnaround on laboratory analyses which, in turn, led to some interesting conclusions regarding the kinetic behavior of ΣS^{-2} oxidation. During phases I-1 and I-2, it was necessary, due to the large number of samples collected during a test sequence, to run the analysis on all samples for a given species at one time. As a result, the elapsed time between sampling and analysis averaged between 1 and 2 hours. During phase I-3 operations, a single set of samples was collected in each 24-hour period, permitting a shorter sampling-to-analysis time. In comparing the effluent sulfur species concentrations of phase I-3 to those of phase I-1 at identical operating conditions, phase I-3 values measured consistently higher and somewhat erratic. This led to the speculation that at least one of the oxidation reactions was proceeding much more

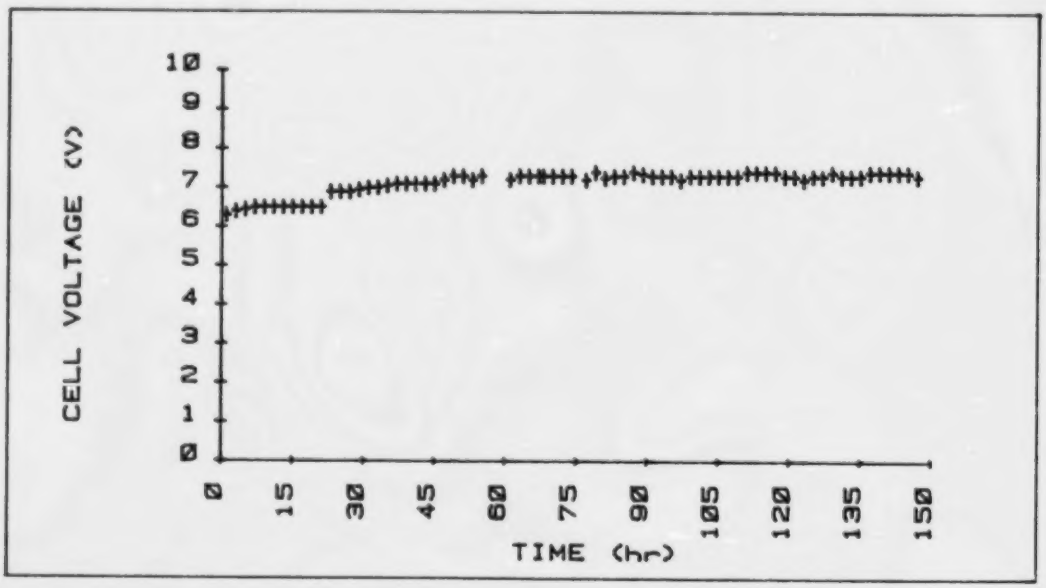


Figure 9. – Cell voltage versus time for phase I-3.

BEST COPY AVAILABLE

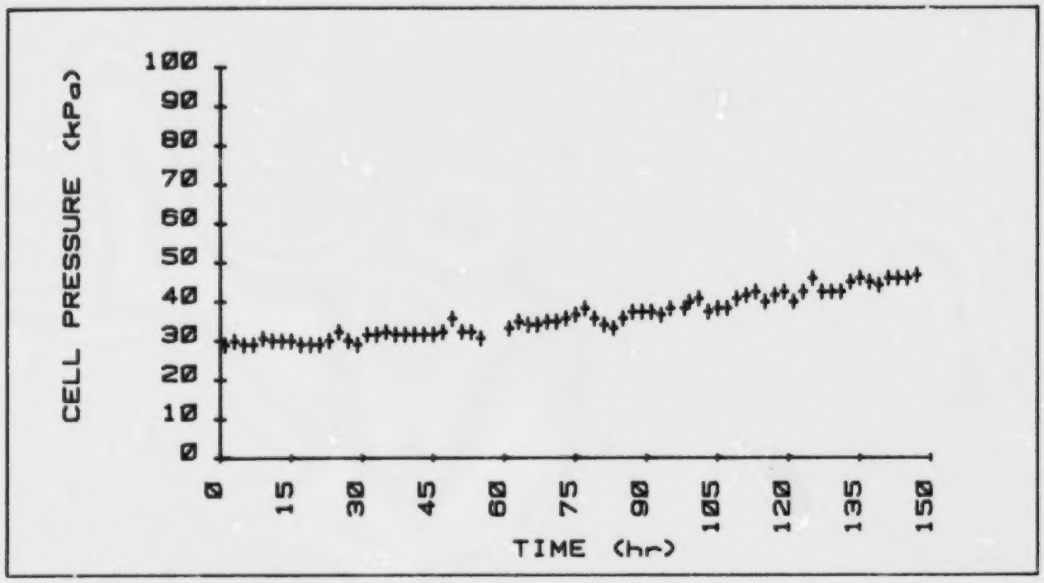


Figure 10. – Cell pressure versus time for phase I-3.

slowly than originally predicted. To test this theory, several effluent samples were collected and analyzed, at intervals, for ΣS^{-2} and $S_2O_3^{-2}$ The results, shown on figure 14, indicate a rapid initial decay of ΣS^{-2} to about 15 mg/L with total oxidation requiring more than 1 hour. Figure 15 shows the decline in effluent residual chlorine level (as OCl^-) versus sampling-to-analysis time.

This kinetic behavior is thought to be related to the relative concentrations of free (gaseous) and dissolved H_2S, and the reactive species, HS^-. At an influent pH of 6.2, dissolved H_2S would be about 15 to 20 percent ionized. Since the concentration of dissolved H_2S, at a given temperature, is directly proportional to its partial pressure, a drop in influent line pressure would result in the liberation, into the gas phase, of some of the dissolved H_2S, reducing the concentration in water of both dissolved H_2S and HS^-. As the oxidation of HS^- proceeds, free H_2S must dissolve into solution and ionize, within equilibria, kinetic, and mass transfer restraints, to satisfy the need for HS^-. It appears that the mass transfer of gaseous to dissolved H_2S may be the rate-limiting step in the oxidation.

Conclusions

- All sulfur species oxidize toward SO_4^{-2} regardless of the flow regime. For phase I-2 operations, oxidation of influent ΣS^{-2} to S^0, the power level required to oxidize ΣS^{-2} to extinction was 6.4 kW, calculated as product of cell current and voltage, or about 2.7 times the theoretical requirement based on the manufacturer's projections for Paradox brine. Figure 8 shows that other species were being oxidized as well. It also appears that reactor residence time had little effect on effluent concentrations.

- Based on data presented on figures 5 and 6, it was determined that the best performance, for oxidation to SO_4^{-2}, was achieved during phase I-1 testing at an operating current of 900 A. These conditions were selected for the extended run (phase I-3).

- The electrical energy requirement for this process is high. Cell voltage readings for phase I-3 remained fairly constant at 7.3 V during the last 95 hours of the 144-hour run (fig. 9) yielding an average power consumption of 6.57 kW (2.90 Wh/L), which would be equivalent to 14.3 MWh/d for a continuous brine flow of 57 L/s. This compares to a predicted power requirement of 5.21 kW (2.30 Wh/L) for oxidation of 77.9 mg/L of ΣS^{-2} to SO_4^{-2} and an estimated requirement of 6.39 kW (2.82 Wh/L) for oxidation of all measured sulfur species to SO_4^{-2}.

- Fouling of the cell electrodes may be a problem for long-term operations. Localized salt deposits, consisting predominantly of NaCl were found within both cells, along with some iron oxide discoloration, subsequent to phase I-3 testing. In addition, precipitated sulfur was found adhering to practically all wetted surfaces within the plant. Acid cleaning of the cells with 10 percent HCl effectively removed the salt deposits but left much of the adhering sulfur.

- The rate of oxidation of sulfide in Paradox brine is much slower than originally anticipated. During

BEST COPY AVAILABLE

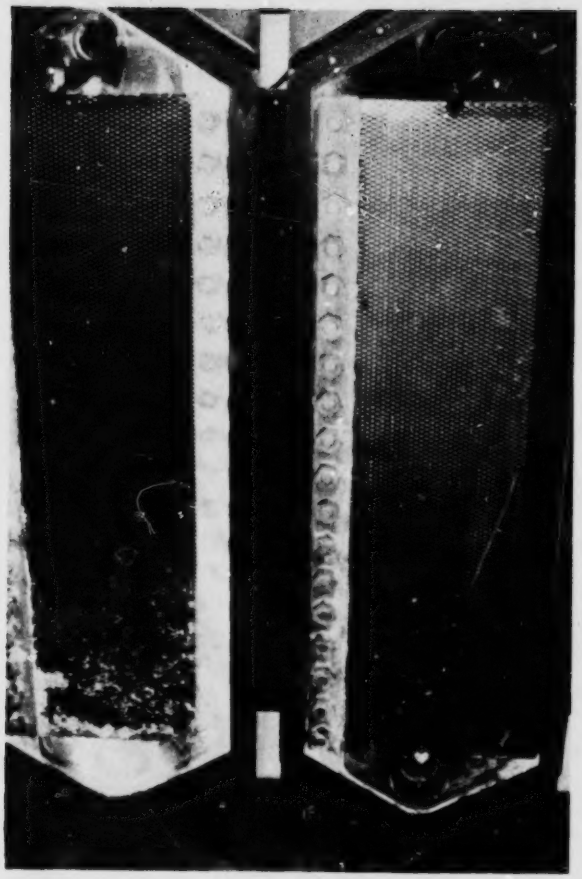


Figure 11. – Cell electrodes subsequent to phase I-3 testing. Direction of flow is from lower left to upper right. P801-D-80930.

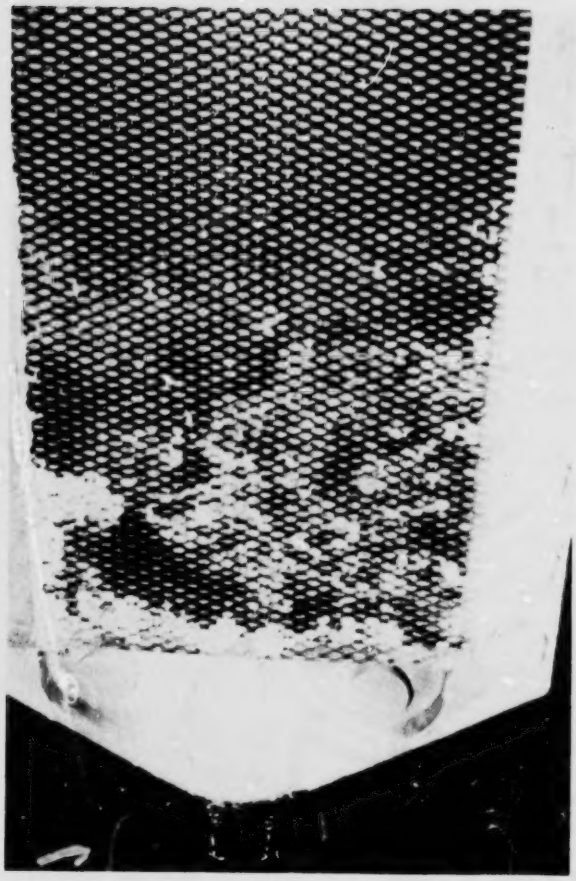


Figure 12. – View showing sodium chloride and sulfur deposits at inlet of cell 1. P801-D-80931.

phase I-3 operations, complete decay of influent ΣS^{-2} required more than 1 hour (fig. 14). The mass transfer of gaseous to dissolved H_2S is thought to be the rate-limiting step in the oxidation.

PHASE II TESTING: NICKEL-CATALYZED AIR OXIDATION

The work in this phase of testing involved the field evaluation of a nickel-catalyzed aeration process for the oxidation of aqueous sulfide in Paradox brine to elemental sulfur or higher valence state. The objectives of the testing were to determine the significance of selected variables in their effect on sulfide oxidation and to establish, through regression analysis, design equations for predicting oxidation efficiency as a function of these variables.

The program involved a series of statistically designed parametric tests to determine the effects of catalyst concentration, column pressure, air mass-flow rate, diffuser pore size, liquid residence time, and temperature on oxidation efficiency in a single-stage, continuous flow, cocurrent aeration column. Based on the results of these tests, an additional phase was added to the program, designated as phase IIa, which investigated a two-stage, gas recycle, aeration system.

This section of the report presents a detailed description of the pilot plant equipment used in both phases of testing (II and IIa), process chemistry, test procedures, results, and conclusions. The results of laboratory-scale tests for the removal of postaeration solids are also discussed.

Process Chemistry and Variable Selection

The theoretical aspects of the oxidation of sulfide by O_2 (oxygen), both with and without catalyst, are discussed by Chen and Morris [1, 2, 3].[2] The oxidation

[2] Numbers in brackets refer to entries in Bibliography.

BEST COPY AVAILABLE

Figure 13 - Cell cover plates subsequent to phase I-3 testing showing discoloration at outlet of cell 2. P801-D-80932

is favored thermodynamically; however, without catalyst, it proceeds at an extremely slow rate. In addition, the uncatalyzed oxidation is characterized by a complex dependence of reaction rates with regard to oxygen and sulfide concentrations, a sensitivity of reaction to impurities, a number of intermediates and products, and a dependence of the initial rate on pH. Combined, these characteristics contribute to a highly complex kinetic behavior.

A number of transition metal ions have been found to catalyze the oxidation strongly in mildly alkaline solutions (pH 7.5 to 9.5) where HS^- is the reactive species. Chen and Morris [2] determined order of catalytic activity to be $Ni^{+2} > Co^{+2} > Mn^{+2} > Cu^{+2} > Fe^{+2} > Ca^{+2}$ or Mg^{+2}. The effect of Ni^{+2} (nickel ion) was found to be so great that 6.0 mg/L of Ni^{+2} caused a decrease in the time for oxidation of 320 mg/L of sulfide at pH 8.65 from several days to a few minutes. Strong accelerating effects of Ni^{+2} were exhibited even at a concentration of 0.3 mg/L.

With an increase of Ni^{+2} concentration, not only is the rate of oxygen uptake greatly increased, the stoichiometry of the reaction shifts from 1.0 mole of O_2 per mole of ΣS^{-2} toward a mole ratio of 0.5. At the same time, sulfur is precipitated visibly at a pH where this was not observed in the absence of Ni^{+2}. The effect of change in stoichiometry with catalyst concentration is depicted on figure 16 for the test conditions listed. Also shown on figure 16 is the significant reduction in reaction time obtained with increasing catalyst addition.

The stoichiometric relationship between ΣS^{-2} and O_2 indicates the reaction products are predominantly S^0 and $S_2O_3^{-2}$ (thiosulfate). As the mole ratio approaches 0.5; that is, at increasing Ni^{+2} concentrations, the product contains proportionally greater quantities of S^0. Oxidation to SO_3^{-2} (sulfite) and SO_4^{-2} (sulfate) does not occur to any significant degree as with the uncatalyzed reaction. It appears that Ni^{+2} accelerates the first stages in the oxidation to such a degree that the normally more rapid later stages cannot keep pace.

The exact mechanism for the catalyst is not known; however, it is strongly suspected that the formation of metal-sulfide complexes may have a direct bearing upon the precipitation of S^0 and the increase of reaction rate. One possible mechanism for the catalysis by metal ions proposed by Chen [2] is:

$$M^{+2} + HS^- \longrightarrow MHS^+$$

$$MHS^+ + O_2 \longrightarrow M^{+2} + S^0 + HO_2^-$$

$$HO_2^- + HS^- \longrightarrow 2OH^- + S^0$$

which reduces to:

$$HS^- + 0.5O_2 \longrightarrow S^0 + OH^-$$

The six independent variables in this program were selected for their expected effect on reaction rate and/or O_2 mass transfer. In most instances, the effects are interrelated. Four of the test variables that should directly affect the rate or extent of reaction are catalyst concentration, air mass-flow rate, liquid residence time, and brine temperature. Catalyst concentration, expressed as mg/L of Ni^{+2}, influences the reaction rate and stoichiometry as previously stated. Air mass-flow rate and residence time both impact total mass transfer of O_2 and, thus, the sulfide-to-oxygen ratio. An increase in solution temperature is expected to accelerate the reaction exponentially.

Four test variables that should directly affect O_2 mass transfer and, thus, reaction rate indirectly, are diffuser pore size, air mass-flow rate, column pressure, and brine temperature. The effect diffuser pore size has on mass transfer depends largely upon the air flow rate. When the rate of airflow is low, the bubble

BEST COPY AVAILABLE

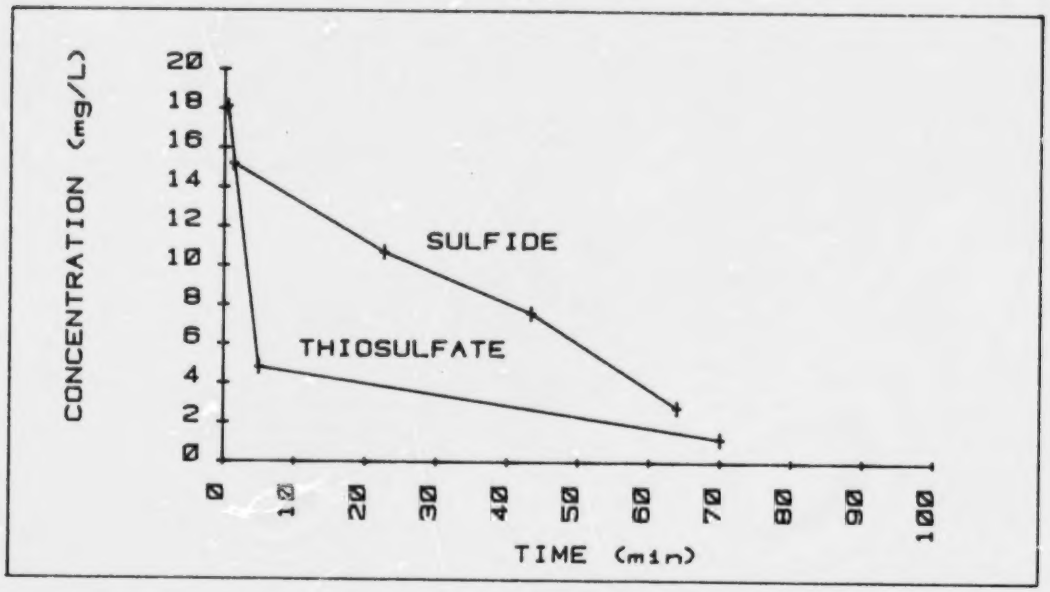


Figure 14. – Sulfide/thiosulfate concentration versus sampling time.

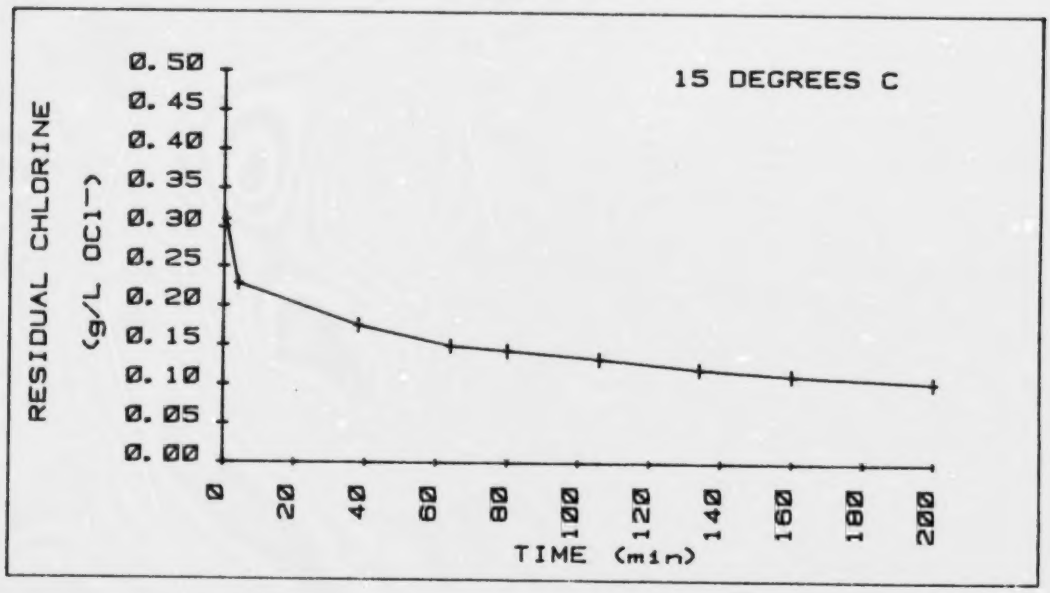


Figure 15. – Residual chlorine versus sampling time.

BEST COPY AVAILABLE

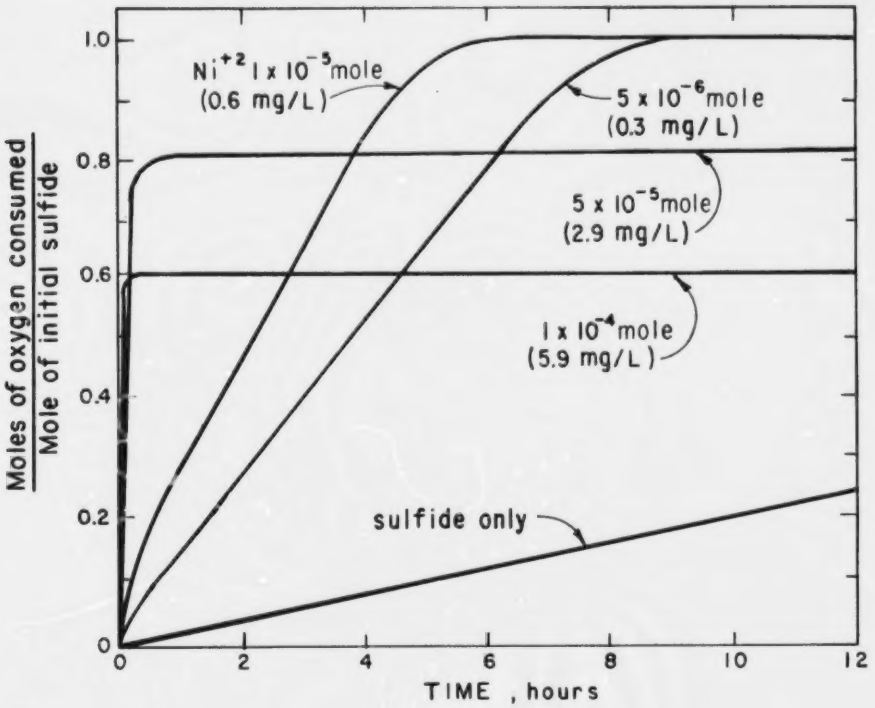


Figure 16. – Catalyst of sulfide oxidation by nickel ion at pH 8.65. $(\Sigma S^{-2})_0 = 1 \times 10^{-2}$ mole (320 mg/L), $O_2 = 0.21$ Atm, and T = 25 °C [2].

size, and consequently the interfacial transfer area, is directly proportional to the diameter of the orifice at which the bubbles are formed. For the general range of flow rates employed in aeration practice, the mean bubble diameter varies exponentially with gas flow rate. This variation in bubble size has two separate effects: (1) smaller bubble sizes promote mass transfer by providing increased transfer area, and (2) larger bubble sizes promote mass transfer by increasing turbulence of the liquid within the column.

Both column pressure and brine temperature influence the solubility of oxygen; pressure directly by changing the partial pressure of oxygen (P_{O_2}), and temperature inversely. Solubility of oxygen also decreases with increasing ionic strength, which is extremely high in Paradox brine. The solubility or saturation limit for a particular gas determines the limiting value of the gas concentration gradient at the gas-liquid interface and, thus, affects the rate of mass transfer.

Previous Investigations

Two separate studies relating to the aeration process were performed prior to the work presented in this report. The first involved bench-scale tests to screen several different treatment processes for sulfide removal in Paradox brine [4]. Processes evaluated included oxidation by diffused air, oxygen, and ozone. Tests using air and oxygen were repeated with a small amount of $NiSO_4$ (nickel sulfate) added to the brine to catalyze the oxidation. Brine temperature was also varied among runs using air plus $NiSO_4$ catalyst to determine if temperature would be an important factor determining overall rate and conversion.

Results indicated that bubbling air or pure oxygen through Paradox brine (a sample containing 45 mg/L of sulfide) without catalyst was ineffective in controlling the release of H_2S (hydrogen sulfide) in gaseous form. Addition of $NiSO_4$ catalyst (2 mg/L as Ni) prior to aeration resulted in significant oxidation and retention of sulfide. No improvement in retention was observed when using pure oxygen plus catalyst as compared to air plus catalyst. Lowering the water temperature from 24 to 12 °C did not indicate a significant change in sulfide retention.[3] Using ozone

[3] Temperature was shown to have a significant effect during phase II testing.

BEST COPY AVAILABLE

(about 80 times the minimum calculated amount to oxidize all H_2S to S^0) with no catalyst resulted in complete disappearance of sulfide precipitates and H_2S odor.

Physical configuration of the test apparatus apparently resulted in a mass-transfer controlled oxidation of H_2S when using air plus catalyst, which suggests a relatively fast oxidation reaction. However, the experiments were not designed to quantify reaction rate or ultimate extent of reaction; thus, no conclusions regarding these variables in a larger scale system could be made.

The second study involved a brief field evaluation, at the Paradox site, to further investigate the nickel-catalyzed aeration process in a continuous flow mode [5]. Test equipment and procedures were basically the same as used for the present work (see next section – phase II), with the following exceptions: (1) testing was designed to provide feasibility data only; i.e., the total number of test runs were limited in number and independent variables were evaluated over relatively narrow control ranges, insufficient to support meaningful regression analysis, (2) no attempt was made to quantify H_2S gas losses from the process effluent stream although some qualitative determinations were made, and (3) a colorimetric (methylene blue) method of analysis was used for total sulfide measurement, as opposed to the titrimetric (iodine) standard method used in phase II. The latter procedure employed a sulfide concentration step in which interfering substances were removed.

The data indicated significant sulfide removals to below 1.0 mg/L of S^{-2} in filtered effluent brine while operating at a catalyst concentration of 1.5 mg/L of Ni^{+2} and a liquid residence time of 11.5 minutes. Subsequent to testing, however, it was learned that color formation in the sulfide analyses may have been partially inhibited by high concentrations of SO_3^{-2} and $S_2O_3^{-2}$ in the brine, which would result in lower ΣS^{-2} measurements than actually present. This suspicion was substantiated when laboratory results were compared with data from the present investigation.

Phase II – Single-Stage Aeration

The test objectives for this phase were to determine the significance of selected variables for their effect on sulfide oxidation and to establish, through regression analysis, design equations for predicting oxidation efficiency in a single-stage, continuous flow, cocurrently operated, diffused aeration column. A series of statistically designed parametric tests were performed on six variables: column pressure, catalyst concentration, residence time, temperature, diffuser pore size, and air mass-flow rate. These variables were identified in the literature and previous testing as having a significant effect on oxygen mass transfer and/or reaction rate.

Plant Description. – Figure 17 shows the flow paths, key items of equipment, and sampling points for the phase II test unit. Briefly, the sequence of operations occurring within the process included: (1) flow rate, pressure, and temperature regulation; (2) catalyst addition and mixing; (3) aeration; and (4) gas separation.

Rate of brine flow to the plant was controlled with a Kates-type FA automatic flow controller (0 to 0.6 L/s), and monitored with a Fischer and Porter series 10A glass rotameter as shown on figure 18. Internal wetted parts of the Kates valve were constructed of 316 stainless steel. The rotameter float was made of Hastalloy C. Calibration of the influent rotameter was checked periodically with a tank and stopwatch to account for any changes in float characteristics. Also shown on figure 18 is the Fortin-type barometer used to adjust effluent H_2S measurements for atmospheric pressure.

Influent brine temperature was adjusted with a 32-kW Chromalox in-line heater (three-phase, 480 V) and associated solid-state controller, shown on figure 19. The heater originally employed a Fenwal controller and mechanical contactor. This method of control allowed sawtooth-pattern fluctuations in the downstream brine temperature of nearly ± 5 °C, which was unacceptable. A solid-state relay was subsequently added which reduced this fluctuation to within ± 0.5 °C. The heating elements and internal wetted surfaces of the containment vessel were lined with Hastalloy C. Process temperatures were monitored at the points depicted on figure 17 using copper constantine, 316 stainless steel sheathed thermocouple assemblies, and a Fluke digital thermometer/multipoint switch unit.

Pressure on brine entering the plant was maintained at about 310 kPa (gauge) to prevent the liberation of H_2S in the pipeline. Plant operating pressure was regulated with a back-pressure valve located immediately downstream of the aeration columns. Pressures within the system were monitored using Kavlico transducers with a rating of 0 to 415 kPa at an output voltage of 0 to 5.0 V d.c.

Catalyst ($NiSO_4 \cdot 6H_2O$) was prepared in a batch tank (fig. 20) and metered to the brine flow, downstream of the influent temperature adjustment, with a BIF diaphragm feed pump. A 25-mm-diameter, six-section PVC (polyvinyl chloride) static mixer was used to assure adequate mixing of the catalyst. Calibration curves were prepared for the metering pump at each of the operating pressure levels to establish

BEST COPY AVAILABLE

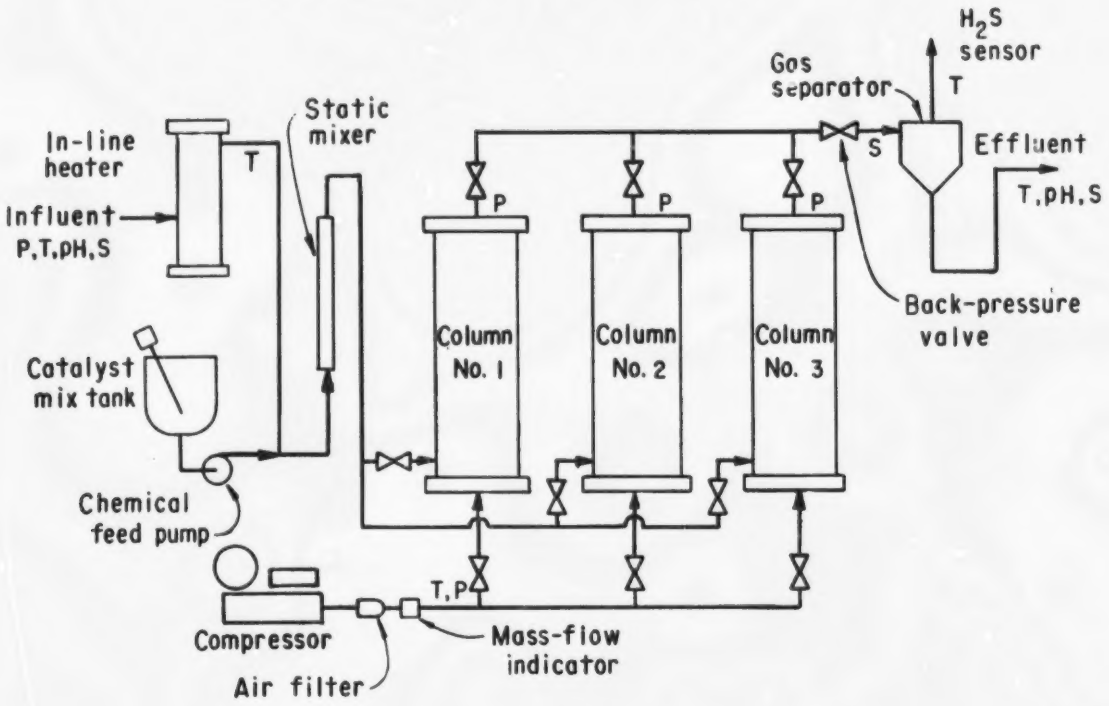


Figure 17. – Flow diagram for phase II aeration unit. Transducers are shown as pH, T (temperature), P (pressure), and S (sampling points).

pump settings. However, data values recorded for catalyst flow rates were based on time-volume changes in the batch tank. A local municipal water supply was used to prepare the catalyst batch solutions. The large volume of dilution water required per day, about 300 L, and the remote location of the site precluded the use of distilled water for this purpose. The Ni^{+2} concentrations in the batch solutions should have been high enough to mask any potential catalytic or inhibiting effect attributed to constituents in the water.

Aeration was accomplished in vertically mounted, flanged columns constructed of 300-mm PVC pipe sections, as shown on figure 21. Three separate columns were provided, each with porous ceramic diffusers of a different pore diameter range: 7 to 10, 44 to 55, and 87 to 108 μm, as determined by the manufacturer. Four circular diffusers, measuring 100 mm in diameter and 13 mm in thickness, were mounted in each baseplate for a total diffuser surface area per column of 327 cm^2. The columns measured 1520 mm in height with an inside diameter of 295 mm, for a total volume of about 103 L. System plumbing allowed selection of an individual column, depending on the diffuser pore size required for a particular test run. All columns were insulated with 75-mm fiberglass to limit heat loss; i.e., to retain the set-point temperatures.

Air supplied to the on-line column was metered using a Hastings linear mass-flowmeter with a range of 0 to 50 sL/min (standard liters per minute, which is flow measurement adjusted to standard temperature and pressure). Volumetric air flow rate, temperature, and pressure measurements were also taken as a check on mass-flow readings. The air supply was filtered using a Norgren 10-mm, air-line filter. The compressor, mass-flowmeter, and related equipment are shown on figure 22.

Brine exiting the aeration columns contained an air-H_2S gas phase which had to be separated from solution to accommodate analytical procedures for measuring residual sulfide levels in the two phases individually. A gas-liquid separator of the scale required to perform this function was not available commercially; therefore, a unit was designed and built in our laboratories (fig. 23). Phase separation was induced by the drop to atmospheric pressure at the backpressure valve and the impingement of brine against the back surface of the separator. Figure 23

BEST COPY AVAILABLE

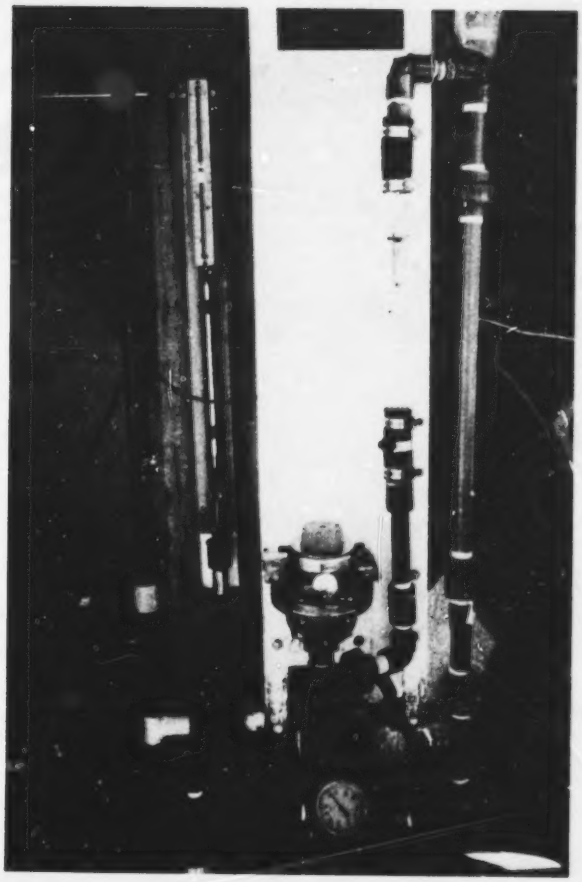


Figure 18. – Influent flow regulation equipment and Fortin barometer. P801-D-80933.

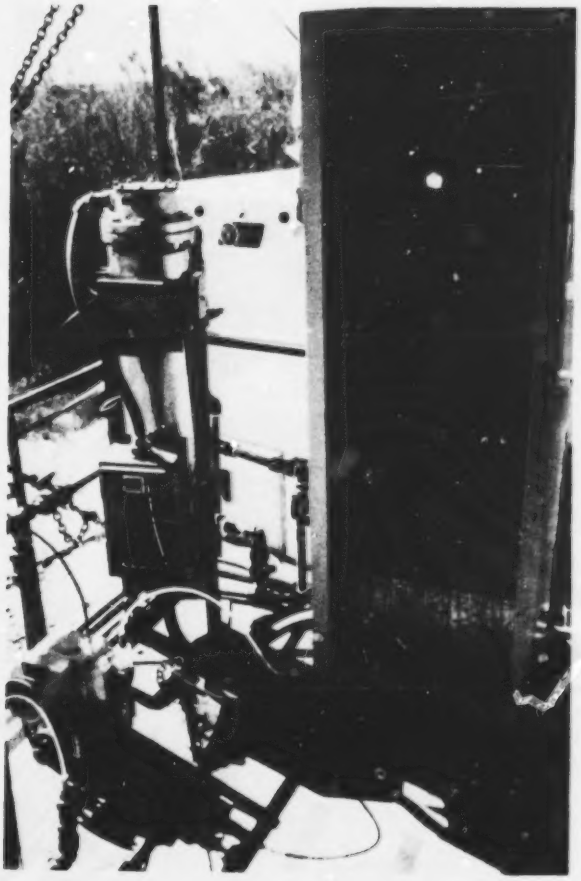


Figure 19. – Chromalox in-line brine heater and associated solid-state controller. P801-D-80934.

also shows the sampling points for effluent brine (sample cock with tubing attached) and effluent gas (immediately beneath the roofline).

All piping, valves, and fittings in contact with the brine stream were constructed of schedule 80 PVC. Brine lines downstream of the plant intake were all 25 mm in size.

Test Procedures. – Parametric testing involved the use of a systematic experimental design, developed by Box and Behnken [6], to establish relationships between dependent and independent process variables. The basic design for 6 independent variables consisted of 3 operating levels (high, low, and midpoint) for each independent variable, and 54 experimental runs or observations. The independent or control variables $X_1 - X_6$, dependent variables or responses $Y_1 - Y_3$, and independent variable levels used during this test phase are presented in table 3. The principles governing experimental strategy encourage the exploration of each independent variable over a sufficiently broad range to assure the experimental region of interest is adequately covered. The levels selected reflect this concept commensurate with process equipment limitations.

Table 4 presents the 54 experimental runs required by the design. The order in which the runs were completed was randomized to limit bias error. Randomization with respect to variable X_5 (diffuser pore size) was compromised somewhat to facilitate plant operations; however, the variable was repeated in sufficient groupings to limit the effects of the compromise.

Data from these experiments were analyzed using an HP (Hewlett-Packard) 9835A desktop computer with HP multiple regression software.

Analytical Methods. – Two separate laboratory analyses were required: (1) total sulfide, ΣS^{-2} (summation of H_2S, HS^-, and acid soluble metal sulfides) for both

BEST COPY AVAILABLE

Figure 20. – Catalyst batch tank and mixer. P801-D-80935.

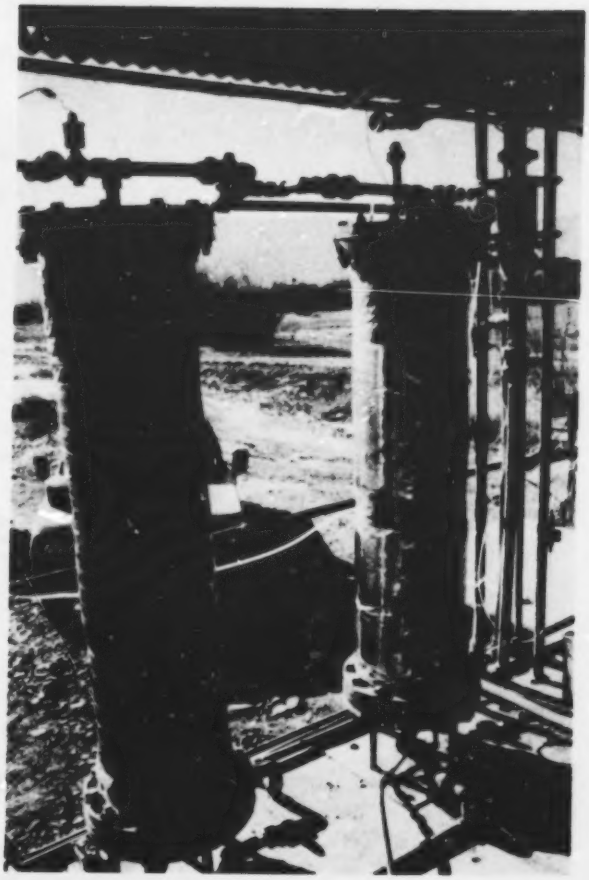


Figure 21. – Two of the three insulated aeration columns used in phase II testing. P801-D-80936.

filtered and unfiltered effluent brine samples, and (2) H_2S concentration in the effluent gas.

The analysis for brine followed the titrimetric (iodine) procedure for total sulfide, outlined in reference [7], with some minor modifications. The first half of the analysis involved the removal of interfering substances and the precipitation of the sulfide. Interferences due to partially oxidized or reduced species in the brine, present initially or as a result of the oxidization process, were of primary concern. Species such as sulfite, thiosulfate, and iodide might be present in concentrations which could alter the iodine endpoint in the titration. The sample pretreatment procedure was followed with one exception: a centrifuge was used instead of filtration or settling in the concentration step to shorten analysis time.

Prior to the fieldwork, a study was performed to verify the precision and accuracy of the standard method of sulfide analysis on Paradox brine. Results of the study, shown in table 5, indicate no apparent problem with the Paradox brine analyses. The precision of ± 0.05 mg/L for the brine was based on a standard deviation of the four samples. Reference [7] lists a precision of ± 0.10 mg/L. Therefore, the substitution of a centrifuge for the filtration step did not significantly alter the precision of the method.

Two different procedures were used to measure H_2S concentrations in the effluent gas: (1) an adaptation of the titrimetric (iodine) standard method, and (2) Bendix/Gastec direct reading detector tubes. Readings from the detector tubes were used primarily as a check against the standard method and as a means of rapid, intermediate analysis during a test run. Data from both methods were used in subsequent regression work.

No pretreatment step was necessary in the titrimetric procedure because sulfide collected in the gas

BEST COPY AVAILABLE

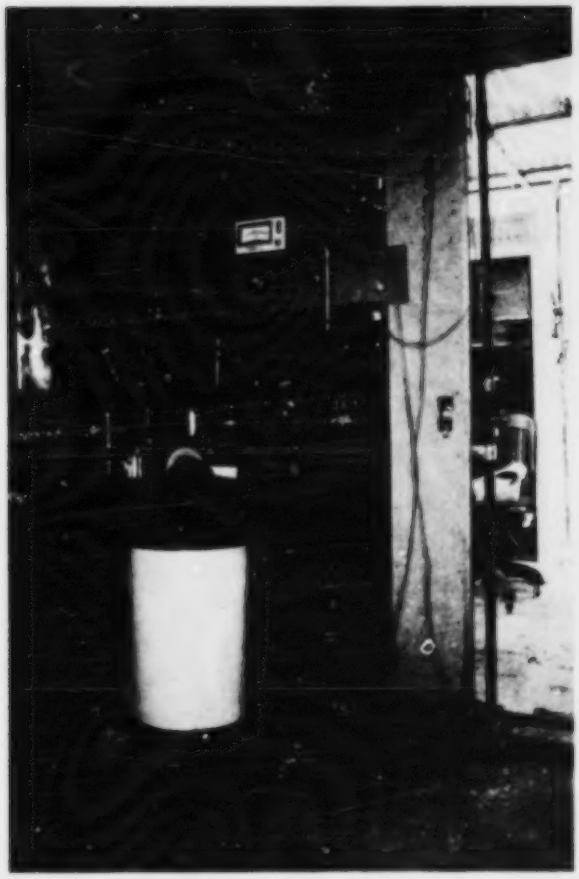


Figure 22. – Compressed air supply and Hastings linear mass-flowmeter. P801-D-80937.

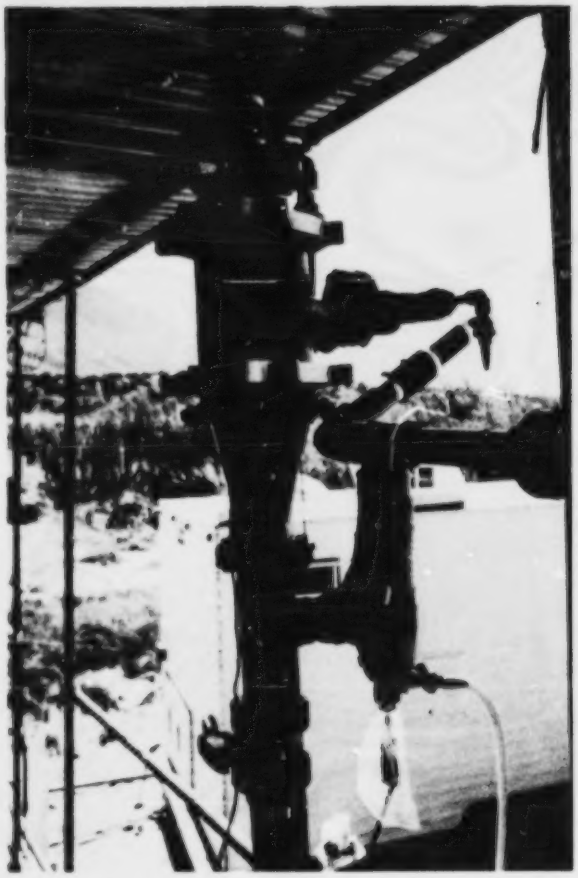


Figure 23. – Gas-liquid separator and effluent sampling points. P801-D-80938.

phase was free from interferences present in the brine. In this analysis, a known standard volume of effluent gas was passed through two absorption flasks in series, both containing a zinc acetate solution to trap H_2S as zinc sulfide. Excess iodine was then added to the zinc sulfide suspension to react with the sulfide under acidic conditions. The resulting solution was then back-titrated with sodium thiosulfate, using a starch indicator, to determine the quantity of iodine consumed by the sulfide.

The sampling device used for this procedure is shown on figure 24. Effluent gas was drawn from the gas separator with a variable-speed Masterflex tubing pump. Volumetric flow rate was maintained at 500 mL/min using a Cole-Palmer laboratory flowmeter. Sampling time was adjusted for gas temperature and atmospheric pressure to yield a gas sample volume of 2.0 sL. This sampling technique worked well when measuring low to moderate H_2S concentrations. At high concentrations, however, so much zinc sulfide precipitate was generated that it adhered to the absorption flask walls and tubing, making quantitative removal difficult.

The detector tubes used were in three concentration ranges: 10 to 240 p/m, 100 to 3200 p/m, and 0.1 to 4.0 percent. After determining the appropriate concentration range, an average of three separate readings was taken for each observation. This average value was then adjusted for atmospheric pressure and recorded.

Results and Discussion. – Phase II test data are presented in table A-1 of appendix A. A total of 74 observations or test runs were completed, 54 associated with the original experimental design, as shown in table 4, plus an additional 20 replicates of selected runs. These additional (subscripted) observations include some runs completed prior to initiation of the test series and others that were required to resolve specific concerns about the data. The first six columns of the data in table A-1 ($X_1 - X_6$) list

BEST COPY AVAILABLE

Table 3. – Phase II test variables and independent variable levels.

Variable	Description	Level			Units
		low	medium	high	
X_1	Column pressure	10	80	150	kPa (gage)
X_2	Catalyst concentration	0.9	4.7	8.5	mg/L of Ni^{+2}
X_3	Brine residence time	9	17	25	min
X_4	Brine feed temperature	12	18	24	°C
X_5	Diffuser pore size (range)	7-10	44-55	87-108	μm
X_6	Air mass-flow rate	10	35	60	sL/min
Y_1	Effluent ΣS^{-2} concentration (filtered)	–	–	–	mg/L
Y_2	Effluent ΣS^{-2} concentration (unfiltered)	–	–	–	mg/L
Y_3	Effluent H_2S gas concentration	–	–	–	mg/m^3

measured independent variable levels, and the last four columns ($Y_1 - Y_4$) list dependent variables or responses. Dependent variables Y_1 to Y_3 were also assigned X-variable names (X_7, X_8, and X_9/X_{10}) for use in the regression analysis.

Total sulfide, ΣS^{-2}, concentrations were measured in both unfiltered and filtered effluent brine samples to determine the percentage that may be attributable to the presence of acid soluble metal sulfides or other soluble sulfide complexes. Filtration was performed under pressure through a 0.45-μm Millipore filter pad. The average difference in ΣS^{-2} concentrations due to filtration among all 74 observations was 13.1 percent. Metal sulfides are formed as intermediates in the oxidation reaction and should be removed along with the sulfur in a subsequent multimedia filtration process. Filtered effluent ΣS^{-2} concentrations X_7 were therefore used as an indicator of removal efficiency in the brine stream.

Effluent H_2S gas concentration measurements by the titrimetric (iodine) method of analysis were consistently lower than those obtained using the detector tubes, by an average of about 23 percent. Figure 25 shows data from one analytical method plotted against the other. There appears to be a high correlation between the two sets of data; i.e., a uniform divergence with increasing concentration. Possible causes for the divergence might relate to: (1) inability to quantitatively recover zinc sulfide precipitate from the reaction flasks used to sample effluent H_2S gas, and/or (2) inadequacy of zinc acetate solutions in two reaction flasks to totally contain or trap the H_2S sample at higher concentrations.

In the primary region of interest; i.e., below about 5000 mg/m^3 of H_2S, the absolute differences between measurements from the two methods were relatively small. Therefore, it was decided to run the regression analysis using both sets of data to determine which data provided the best fit.

A second degree polynomial approximation was used in modeling the process data. The terms to which the data were fit are presented in table A-2 of appendix A. Variables X_{12} through X_{32} are tranformations of the independent variables $X_1 - X_6$, which provide the remaining terms of the polynomial. Five additional cross products, $X_{33} - X_{37}$, were included to account for suspected three-variable interactions. Variables X_{38} and X_{39} are manipulations of the dependent variables which represent the percent ΣS^{-2} remaining (based on a mean influent concentration of 83.34 mg/L of ΣS^{-2}) in the effluent brine and gas streams, respectively. Variable X_{40}, total percent sulfide remaining, is the sum of X_{38} and X_{39}. The complete data matrix for phase II is also shown in table A-2.

Table 6 presents a summary of the results of two phase II regression analyses relating to effluent brine and effluent gas data. Associated AOV (analysis of variance) tables and standarized residual plots are presented in tables A-3 and A-4, and figure A-1 in appendix A. Both regressions were performed using all 74 observations.

The correlation coefficients listed in tables A-3 and A-4 indicate the percentage of variance in the data accounted for by the regression equation; i.e., a measure of the strength of association between the independent and dependent variables. Correlation for the phase II effluent gas data was comparatively weak, using data generated by either of the two gas sampling methods. A plot of the regression residuals (fig. A-1, app. A) indicates a normal distribution of error over the range of predicted Y's ($\bar{Y}$). This would suggest that the model is adequate and that the unexplained variance in the data is caused by random error.

The F-ratio is an indicator of the statistical significance of all the regression coefficients taken together. This ratio provides a measure of the "overall" goodness of fit of the regression equation. An

BEST COPY AVAILABLE

Table 4. — Phase II experimental design.

Run No.	X_1 Column pressure (kPa)	X_2 Catalyst conc. (mg/L of Ni^{+2})	X_2 Batch conc. $NiSO_4 \cdot 6H_2O$ (g/L)	X_2 Feed rate (mL/min)	X_2 Pump setting at 78 strokes per min (%)	X_3 Residence time (min)	X_3 Influent flow rate (L/min)	X_4 Feed temp. (°C)	X_5 Diffuser pore size range (μm)	X_6 Diffused air mass-flow rate (sL/min)
1	10	4.7	0.463	560	74	9	12.3	18	44-55	10
2	10	8.5	.839	300	38	17	6.5	24	44-55	35
3	80	4.7	.463	200	29	25	4.4	12	44-55	10
4	80	4.7	.463	300	42	17	6.5	18	44-55	35
5	10	8.5	.839	300	38	17	6.5	12	44-55	35
6	150	4.7	.463	200	31	25	4.4	18	44-55	60
7	80	4.7	.463	560	78	9	12.3	24	44-55	60
8	80	4.7	.463	300	42	17	6.5	18	44-55	35
9	80	4.7	.463	300	42	17	6.5	18	44-55	35
10	150	4.7	.463	200	31	25	4.4	18	44-55	10
11	10	4.7	.463	300	38	17	6.5	12	87-108	35
12	10	4.7	.463	300	38	17	6.5	24	87-108	35
13	80	8.5	.839	200	29	25	4.4	18	87-108	35
14	150	4.7	.463	300	45	17	6.5	24	87-108	35
15	80	8.5	.839	560	78	9	12.3	18	87-108	35
16	80	8.5	.839	300	42	17	6.5	18	87-108	60
17	80	8.5	.839	560	78	9	12.3	18	7-10	35
18	150	4.7	.463	300	45	17	6.5	24	7-10	35
19	80	0.9	.089	560	78	9	12.3	18	7-10	35
20	80	0.9	.089	300	42	17	6.5	18	7-10	60
21	80	8.5	.839	300	42	17	6.5	18	7-10	60
22	80	8.5	.839	300	42	17	6.5	18	7-10	10
23	150	4.7	.463	560	82	9	12.3	18	44-55	10
24	80	4.7	.463	560	78	9	12.3	24	44-55	10
25	10	4.7	.463	200	27	25	4.4	18	44-55	60
26	80	4.7	.463	200	29	25	4.4	12	44-55	60
27	80	4.7	.463	200	29	25	4.4	24	44-55	10
28	80	4.7	.463	560	78	9	12.3	12	44-55	60
29	150	8.5	.839	300	45	17	6.5	12	44-55	35
30	80	4.7	.463	300	42	17	6.5	18	44-55	35

BEST COPY AVAILABLE

BEST COPY AVAILABLE

Table 4. — Phase II experimental design.—Continued

Run No.	X_1	X_2				X_3		X_4	X_5	X_6
	Column pressure (kPa)	Catalyst conc. (mg/L of Ni^{+2})	Batch conc. $NiSO_4 \cdot 6H_2O$ (g/L)	Feed rate (mL/min)	Pump setting at 78 strokes per min (%)	Residence time (min)	Influent flow rate (L/min)	Feed temp. (°C)	Diffuser pore size range (μm)	Diffused air mass-flow rate (sL/min)
31	150	4.7	.463	560	82	9	12.3	18	44-55	60
32	10	4.7	.463	560	74	9	12.3	18	44-55	60
33	80	8.5	.839	300	42	17	6.5	18	87-108	10
34	150	4.7	.463	300	45	17	6.5	12	87-108	35
35	80	0.9	.089	560	78	9	12.3	18	87-108	35
36	80	0.9	.089	300	42	17	6.5	18	87-108	10
37	80	0.9	.089	300	42	17	6.5	18	87-108	60
38	80	0.9	.089	200	29	25	4.4	18	87-108	35
39	80	0.9	.089	300	42	17	6.5	18	7-10	10
40	80	0.9	.089	200	29	25	4.4	18	7-10	35
41	10	4.7	.463	300	38	17	6.5	24	7-10	35
42	10	4.7	.463	300	38	17	6.5	12	7-10	35
43	80	8.5	.839	200	29	25	4.4	18	7-10	35
44	150	4.7	.463	300	45	17	6.5	12	7-10	35
45	150	0.9	.089	300	45	17	6.5	24	44-55	35
46	10	0.9	.089	300	38	17	6.5	24	44-55	35
47	10	0.9	.089	300	38	17	6.5	12	44-55	35
48	150	0.9	.089	300	45	17	6.5	12	44-55	35
49	150	8.5	.839	300	45	17	6.5	24	44-55	35
50	80	4.7	.463	200	29	25	4.4	24	44-55	60
51	80	4.7	.463	560	78	9	12.3	12	44-55	10
52	80	4.7	.463	300	42	17	6.5	18	44-55	35
53	80	4.7	.463	300	42	17	6.5	18	44-55	35
54	10	4.7	.463	200	27	25	4.4	18	44-55	10

Table 5. — Verification data for modified titrimetric (iodine) method for total sulfide in Paradox brine.

Sodium Sulfide Standard Solution

Sample No.	mL of Na_2S solution	mL of I_2 solution	mL of PAO[1]	mg/L of S^{-2}
1	1	5	2.75	242
2	1	5	2.80	238
3	1	5	2.75	242
4	1	5	2.80	238

Results: 240 ± 2 mg/L of S^{-2} or precision = 0.83 percent relative standard deviation.

Paradox Valley Brine

Sample No.	mL of brine	mL of I_2 solution	mL of PAO	mg/L of S^{-2}
1	40	5	1.47	8.6
2	40	5	1.49	8.6
3	40	5	1.50	8.5
4	40	5	1.45	8.6

Results: 8.6 ± 0.05 mg/L of S^{-2} or precision = 0.58 percent standard deviation.

Paradox Brine Plus Na_2S Solution

Sample No.	mL of solution	mL of I_2 solution	mL of PAO	True mg/L	Found mg/L	Percent recovery
1	42	10	2.07	19.6	18.0	91.8
2	42	10	2.15	19.6	17.8	90.8
3	42	10	2.15	19.6	17.8	90.8
4	42	10	2.10	19.6	17.9	91.3

Results: Accuracy = 91.2 average percent recovery.

[1] Phenylarsine oxide reagent.

F-ratio value is also associated with each regression coefficient (table A-3), which is used to judge its individual significance. Based on the F-ratio values obtained, all regressions were shown to exhibit a significant fit at the 95-percent confidence interval.

The standard error of estimate represents the average error (residual) in predicting *Y* from the regression equation. The values in table 6 for standard error are in the same units as *Y*; i.e., percent ΣS^{-2}.

The number of terms in each of the regression equations yields a rather lengthy expression; however, only those terms or coefficients significant at the 95-percent confidence interval were included. An alternative approach would be to limit the number of terms to the three or four that provide the greatest contribution to the correlation coefficient (R-squared in AOV tables) and, consequently, accept a reduced correlation and a greater standard error of estimate.

Plots of the phase II regression equations are presented on figures 26 through 29. Figures 26 and 27 pertain to the filtered effluent brine data, and figures 28 and 29 pertain to the effluent gas data. Each figure shows the effect on percent ΣS^{-2} removal of varying air mass-flow rate, catalyst concentration, residence time, and temperature at a fixed diffuser pore size and column pressure. The effect of varying pore size is seen by comparing figures 26 and 27, or 28 and 29, as appropriate. Column pressure is held constant at 10 kPa (lowest operating level) in all of the graphs. Lines of equal H_2S concentration

BEST COPY AVAILABLE

Figure 24. – Effluent H_2S gas sampling apparatus. P801-D-80939.

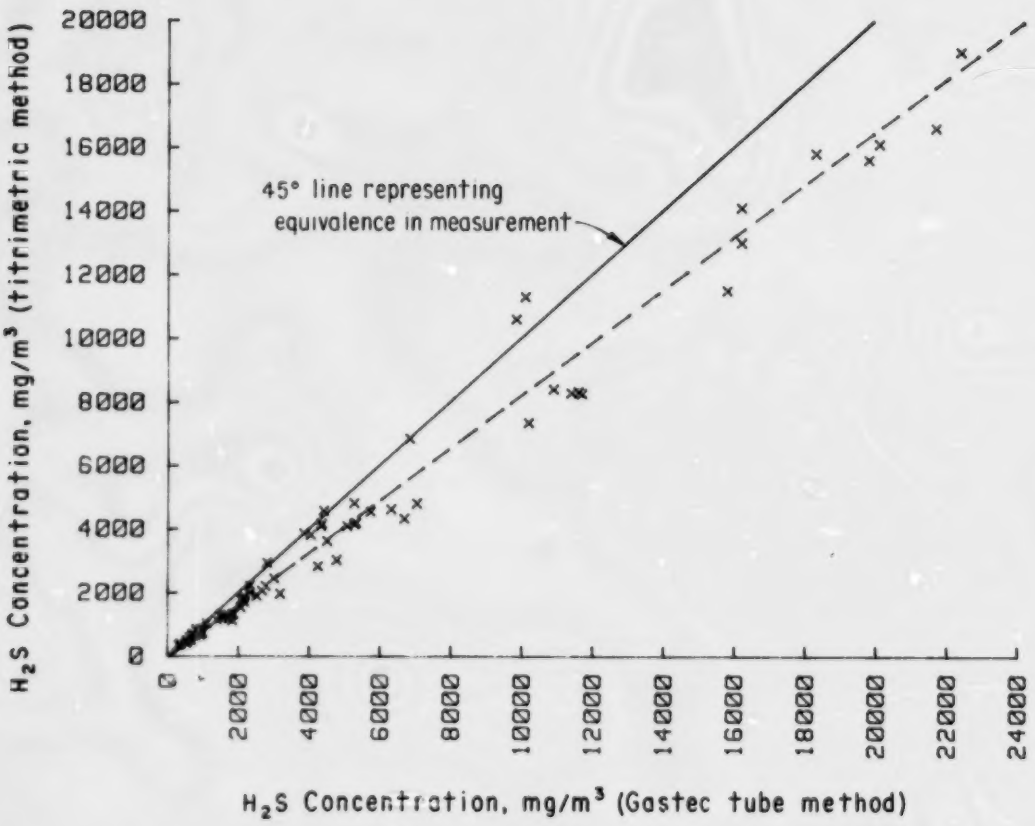


Figure 25. – Comparison of data from two analytical methods for measurement of effluent H_2S gas.

BEST COPY AVAILABLE

Table 6. – Summary of phase II regression results.

	Correlation coefficient, percent	F-ratio value	Standard error, percent of ΣS^{-2}	Number of terms
Effluent brine	85.3	41.2	6.6	9
Effluent gas	59.4	10.4	5.3	9

Equations

Effluent brine:

$$Y = 56.549 + 0.477X_5 - 1.517X_6 + 0.001X_1X_5 - 0.049X_3X_4 - 0.008X_5X_6 - 0.204X_2{}^2 - 0.002X_5{}^2 + 0.015X_6{}^2 + 0.002X_2X_3X_6$$

Effluent gas:

$$Y = 6.630 + 0.457X_3 - 0.505X_4 + 0.355X_5 + 0.454X_6 - 0.014X_3X_6 - 0.005X_5X_6 + 0.0002X_1{}^2 - 0.002X_5{}^2 - 0.002X_2X_4X_6$$

(mg/m³ of S^{-2}) are superimposed over the 15 °C effluent gas plots to show the effects of dilution on H_2S gas concentrations by increasing airflows.

Air mass-flow rate X_6 had the greatest overall influence on oxidation efficiency of the six independent variables tested. Another variable that interacted strongly with airflow was the diffuser pore size X_5. The cross product (X_5X_6) appears in both the effluent brine and gas regression equations shown in table 6. Both of these variables have a significant impact on the size and vertical velocity of the bubbles formed in aeration and the level of solution turbulence and, thus, greatly influence oxygen transfer.

One of the more important observations relating to the phase II data can be seen by comparing plots at the two pore size levels, 8.5 and 49.5 μm. A variation in diffuser pore size is shown to have a much greater effect on predicted ΣS^{-2} removal at low airflow rates than at the higher levels. For example, removal is improved using the 8.5-μm plates at 10 to 35 sL/min. This effect is actually more pronounced at the 10 sL/min airflow level than predicted in the regression equations. Two test runs, 22 and 39, were performed with both airflow rate and diffuser pore size at low operating levels. The residuals for the effluent brine regression (table A-3, app. A) show significant deviation between observed and predicted Y for both of these observations. In each case, the residual is negative; i.e., predicted Y is greater than observed Y. This indicates that runs 22 and 39 resulted in greater ΣS^{-2} removals than are shown by the equation. The same is true of the effluent gas regression. Run 22, which was performed at a high catalyst concentration level, yielded an observed ΣS^{-2} removal (both brine and gas streams combined) of 96.5 percent compared to a predicted efficiency of 71.8 percent.

It is suspected that the parameters affecting bubble formation were changing over the range of air mass-flow rates tested. Three bubble formation regimes are reported in the literature: single-bubble, intermediate, and jet [8]. When the rate of gas flow is low (below a gas-flow Reynolds number of 200), formation is in the single-bubble regime. Bubble size in this flow regime is directly proportional to orifice diameter, and the frequency of formation correspondingly increases with airflow rate. As gas flow through the orifice increases to the intermediate regime (Reynolds numbers between 200 and 2100), the frequency of formation increases more slowly, the bubbles begin to grow in size, and some coalescing begins to occur. Bubble size in this regime varies exponentially with airflow rate. A transition from the single-bubble to intermediate formation in our testing may have resulted in changes in bubble characteristics (size, vertical velocity, and potential for coalescing) that are not fully accounted for by the controlled test variables.

A bubble formation model, developed by Kumar and Kuloor [9], was used to determine orifice Reynolds number and interfacial surface area as a function of diffuser pore size and air mass-flow rate for our system. Model predictions, shown on figure 30, indicate a transition into the intermediate formation regime at an airflow of about 40 sL/min for the 8.5-μm plates. The surface areas shown in the lower graph on figure 30 are based on bubble dimensions

BEST COPY AVAILABLE

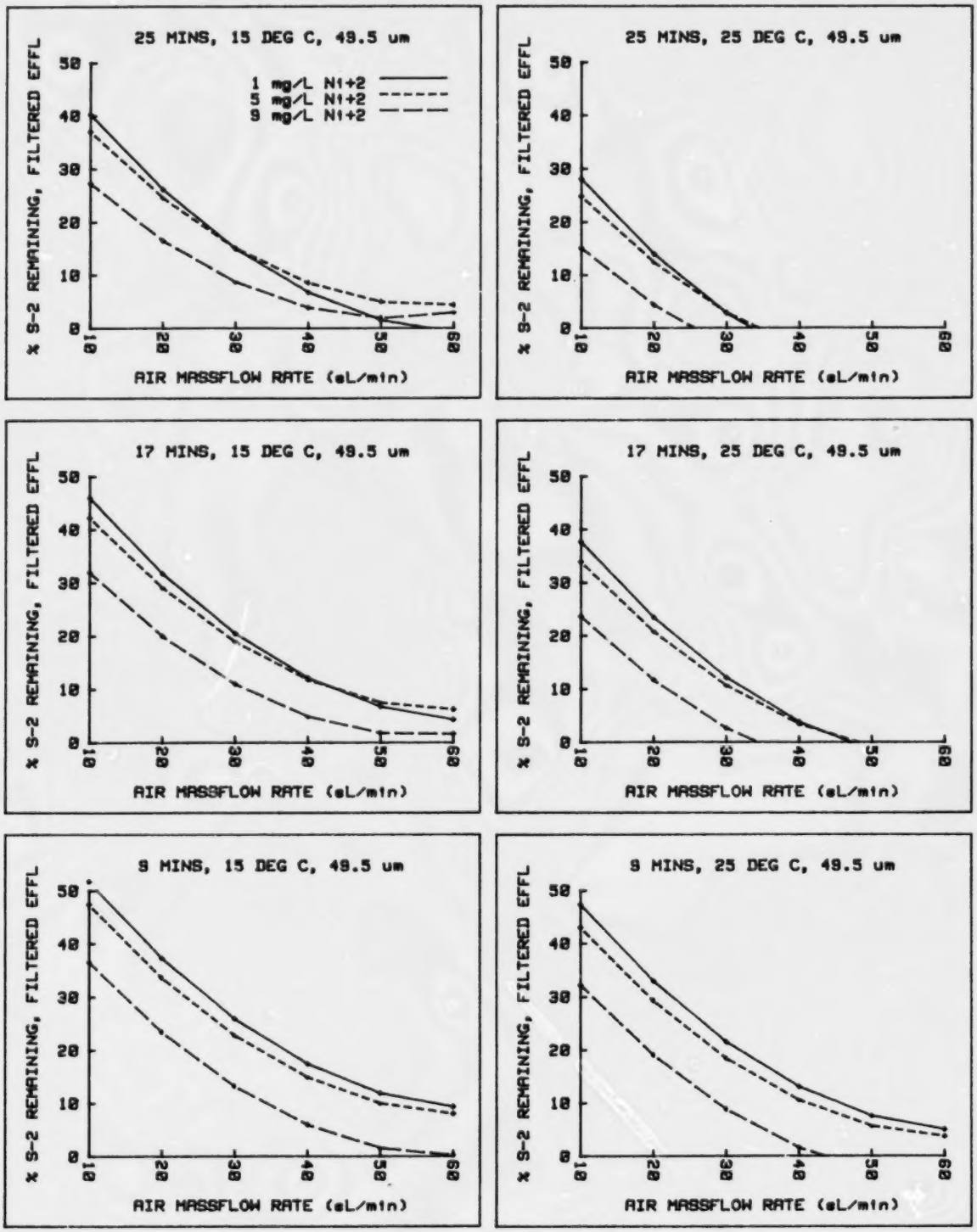

25 MINS, 15 DEG C, 49.5 um
1 mg/L Ni+2
5 mg/L Ni+2
9 mg/L Ni+2
% S-2 REMAINING, FILTERED EFFL
AIR MASSFLOW RATE (aL/min)
25 MINS, 25 DEG C, 49.5 um
17 MINS, 15 DEG C, 49.5 um
17 MINS, 25 DEG C, 49.5 um
9 MINS, 15 DEG C, 49.5 um
9 MINS, 25 DEG C, 49.5 um

Figure 26. – Phase II effluent brine data (49.5-μm mean diffuser pore diameter).

BEST COPY AVAILABLE

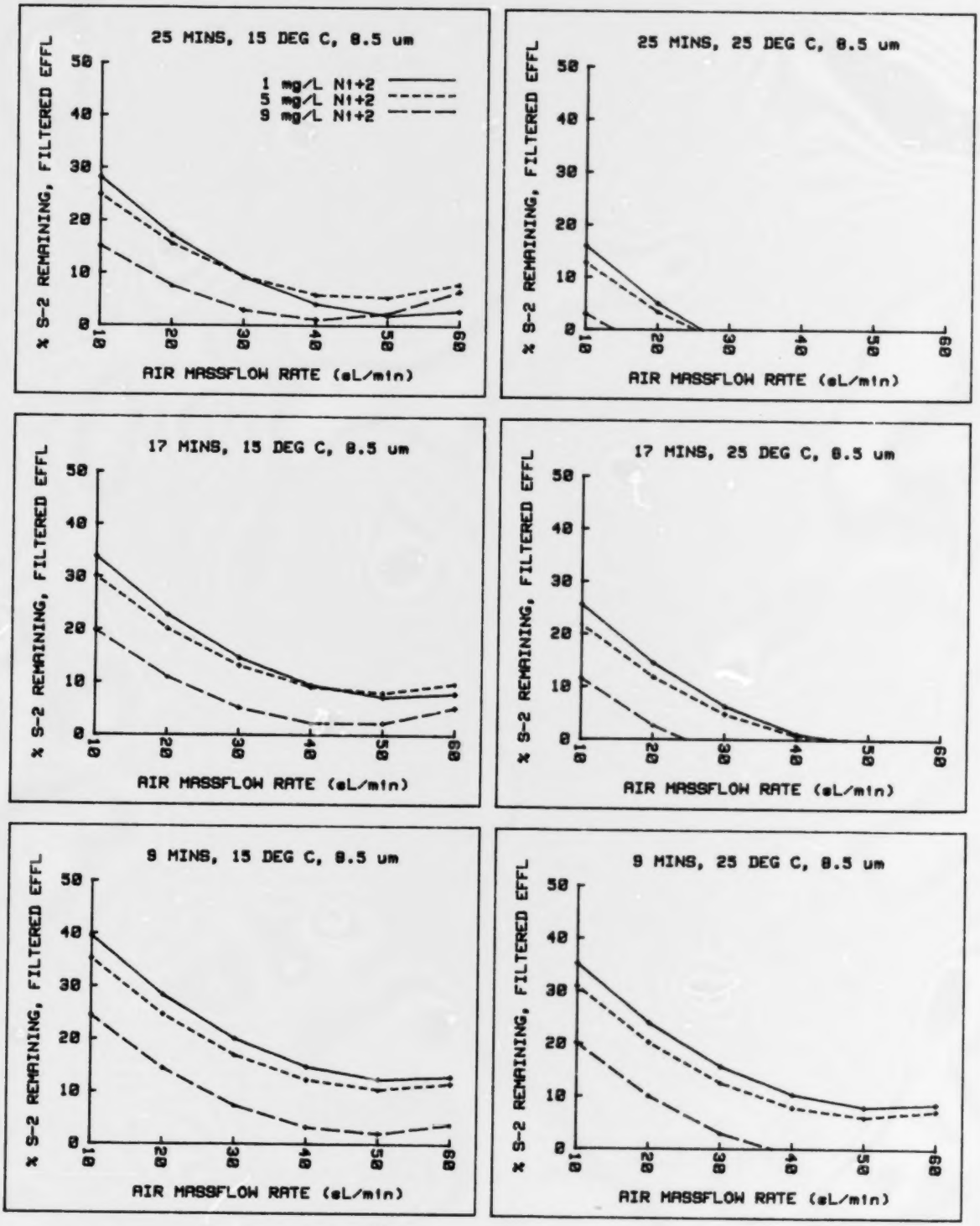

25 MINS, 15 DEG C, 8.5 um
1 mg/L Ni+2
5 mg/L Ni+2
9 mg/L Ni+2
% S-2 REMAINING, FILTERED EFFL
AIR MASSFLOW RATE (eL/min)
25 MINS, 25 DEG C, 8.5 um
17 MINS, 15 DEG C, 8.5 um
17 MINS, 25 DEG C, 8.5 um
9 MINS, 15 DEG C, 8.5 um
9 MINS, 25 DEG C, 8.5 um

Figure 27. – Phase II effluent brine data (8.5-μm mean diffuser pore diameter).

BEST COPY AVAILABLE

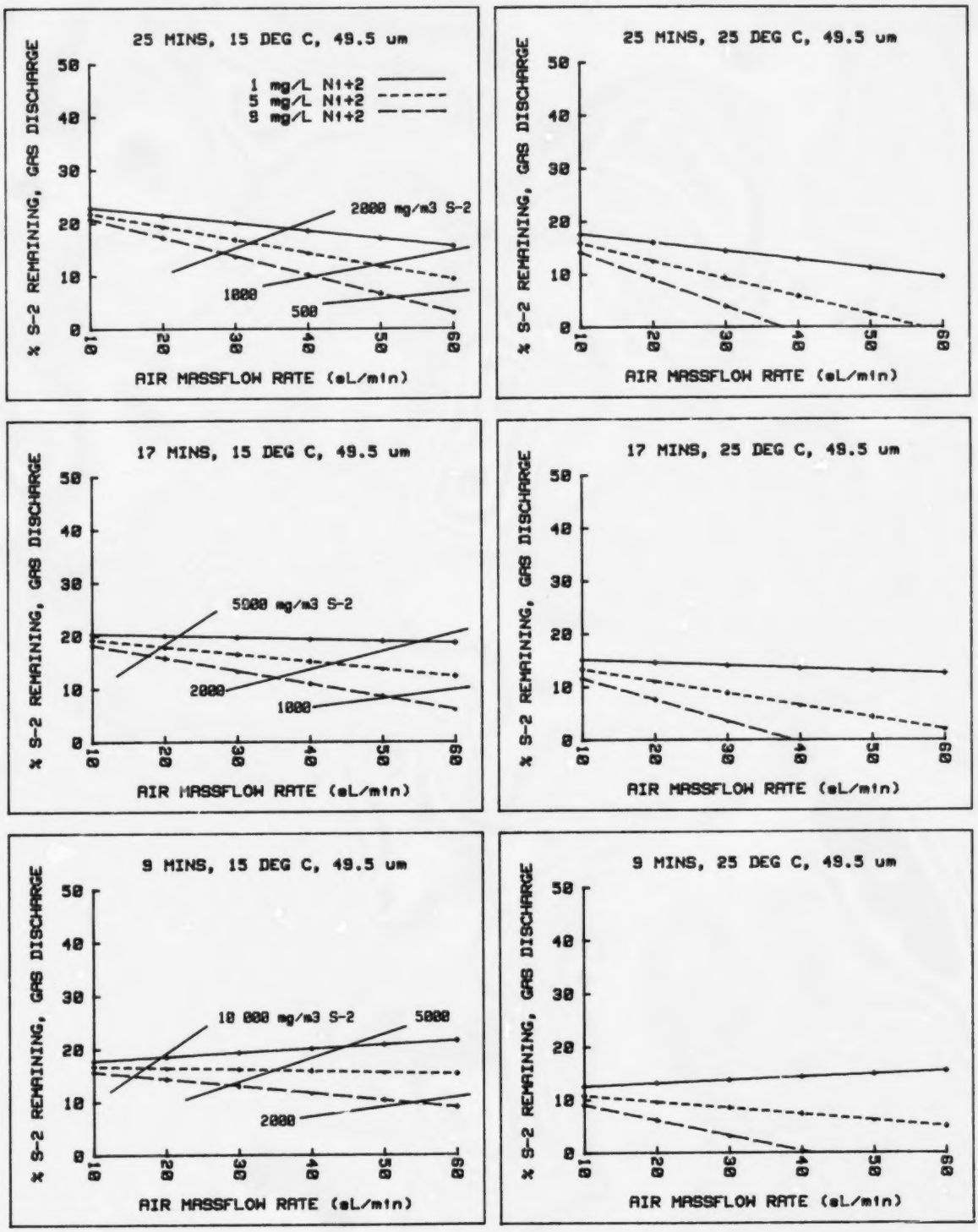


Figure 28. – Phase II effluent gas data (49.5-μm mean diffuser pore diameter).

BEST COPY AVAILABLE

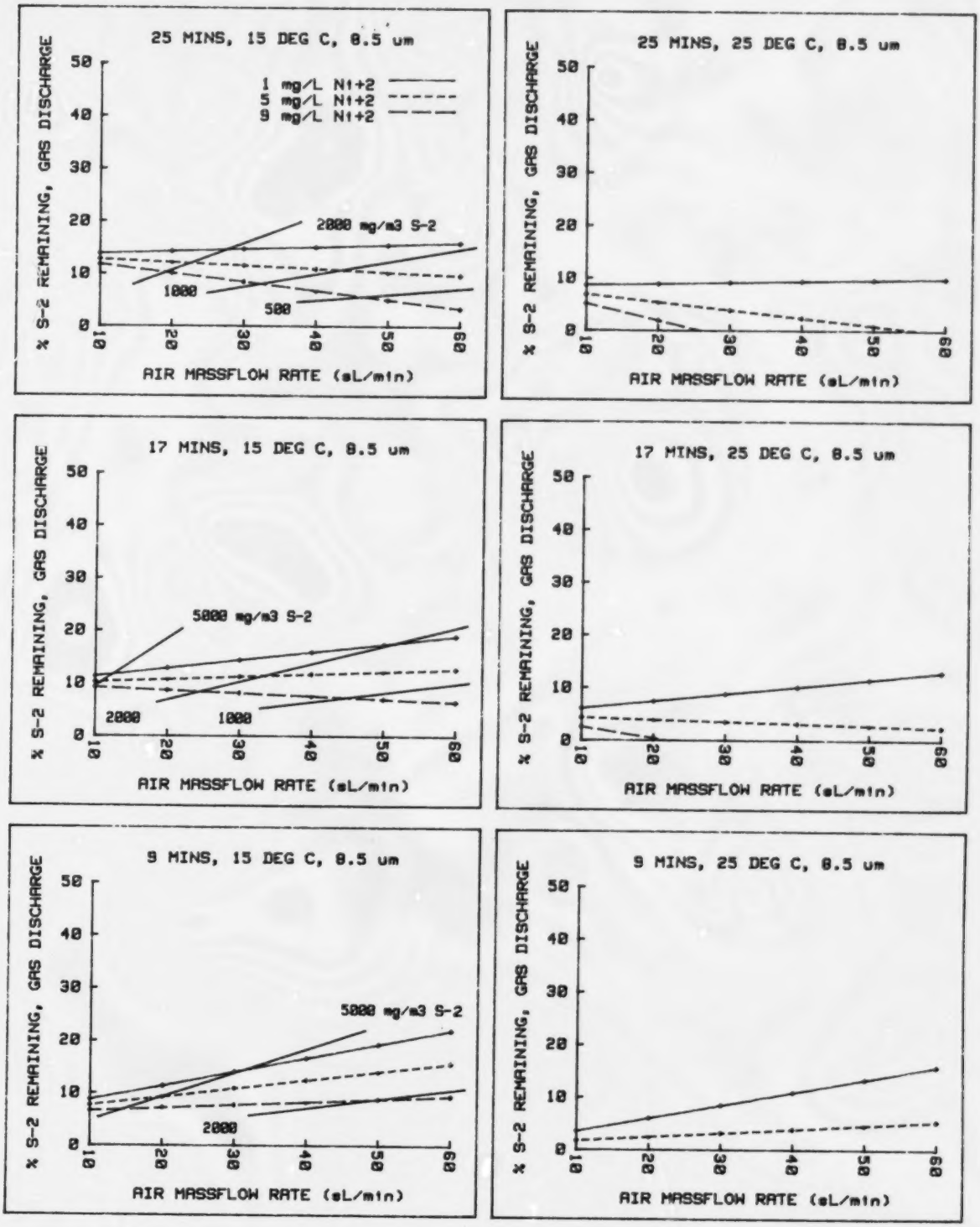


Figure 29. – Phase II effluent gas data (8.5-μm mean diffuser pore diameter).

BEST COPY AVAILABLE

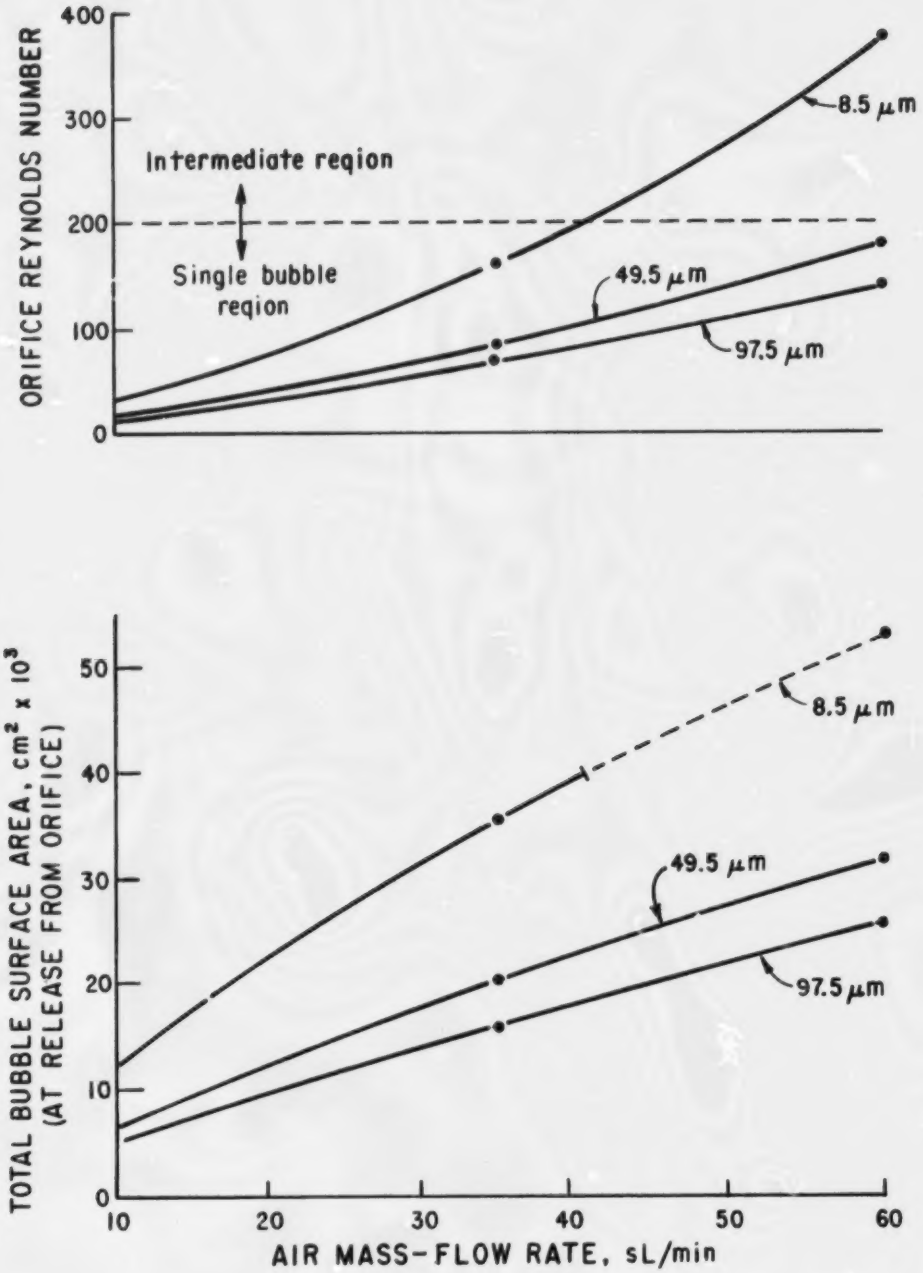


Figure 30. — Variation in orifice Reynolds number and total bubble surface are with diffuser pore size and air mass-flow rate. Based on a model developed by Kumar and Kuloor [9].

BEST COPY AVAILABLE

immediately after release at the orifice and, therefore, do not reflect any increase in bubble size due to coalescing or decreasing pressure upon rising.

The poor fit for observations on runs 22 and 39 may have been caused by data obtained while operating at the mid to high air mass-flow rates with the 8.5-μm diffuser plates. If the diffusers in this airflow regime were approaching or within the intermediate regime as shown on figure 30, coalescing of bubbles may have reduced the effective total O_2 transfer surface area. This uncontrolled effect, which involved 12 observations, could have exerted sufficient influence on the fit to mask or drastically reduce the contribution of the 2 low airflow, low pore diameter data points.

Another interesting interaction can be seen between residence time X_3 and temperature X_4 in the effluent brine regression. At the low residence time (9 min), the effects of temperature appear to be minimal; however, as residence time increases, temperature dependency becomes more pronounced. The overall increase in ΣS^{-2} removal efficiency obtained at 25 °C (combined effluent brine and gas) would suggest a change in rate of reaction, as opposed to a H_2S solubility related phenomenon; e.g., an increased loss of H_2S gas due to stripping. The lower residence (reaction) time is evidently insufficient for the temperature effect to fully manifest itself.

Definite improvement can be seen in oxidation efficiency with increasing catalyst concentrations, particularly between 5 and 9 mg/L of Ni^{+2} in the brine regressions. Also shown is a strong interaction between catalyst concentration and air mass-flow in the effluent gas curves. At the higher airflows and lower catalyst levels, an increasingly greater quantity of H_2S gas is being stripped from solution. This is most prevalent at low residence times where reaction time, and thus the potential for oxidation, is limited.

Column pressure X_1 was included as a variable in the test program because of its expected effect on O_2 mass transfer. Results from earlier bench-scale testing of this process [4] indicated a mass transfer controlled reaction. Therefore, it was assumed that the transfer of O_2, and subsequently oxidation efficiency, could be enhanced by increasing column pressure; i.e., a higher oxygen partial pressure (P_{O_2}) in the vapor phase would create a greater concentration gradient across the phase boundary. Test results actually indicated the opposite effect was occurring. Effluent ΣS^{-2} concentrations increased slightly at higher pressures in both the brine and gas streams. It is possible that the higher pressures may have interfered somehow with diffuser operation causing coalescing of air bubbles. At any rate, column pressure was eliminated as a controlled variable in subsequent phase IIa testing; i.e., no system backpressure was applied.

Figure 31 shows a beaker of freshly sampled, unfiltered, effluent brine containing a suspension of sulfur and dark colored intermediate oxidation products (predominantly NiS). Conversion to sulfur or other acid-insoluble sulfides at this point (discounting

Figure 31. – Typical unfiltered effluent brine sample. P801-D-80940.

BEST COPY AVAILABLE

H_2S losses from the brine due to stripping), based on mean influent and unfiltered effluent ΣS^{-2} concentrations of 83.3 and 15.1 mg/L, respectively, averaged about 82 percent. Oxidation in the sample continued until the solution was clear except for a white colloidal precipitate of sulfur. The time required for this total conversion was not measured but generally amounted to several hours.

Figure 32 shows a photograph of a diffuser plate assembly shortly after completion of phase II testing. One of the concerns in testing, as demonstrated in this photograph, was the potential for diffuser fouling by oxidation products. This could particularly be a problem if air to the diffusers was shut down prior to draining and flushing one or more columns. One of the objectives of the next phase of testing (phase III, which was not funded) was to determine the increase in diffuser headloss with time under extended, continuous operation.

Phase IIa – Two-Stage Aeration

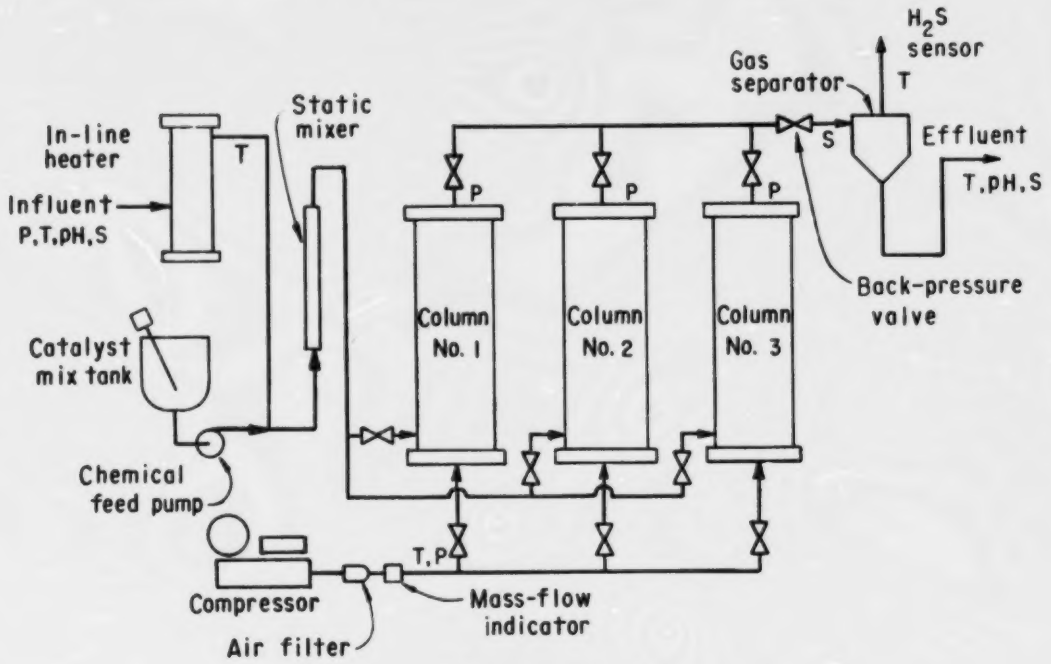
The results of phase II testing, although encouraging, indicated rather marginal performance, particularly relating to the breakthrough of H_2S in the effluent gas stream at low temperature and catalyst levels. Several changes in process design were considered for increasing oxidation efficiency. Two alternatives believed to have the greatest potential were: (1) increasing column depth in the single-stage design to enhance O_2 transfer, or (2) adding a second aeration stage. The latter approach was selected for further study in a new phase of testing, designated phase IIa. The test objectives, parametric test procedures, and analytical methods were generally the same as those of phase II. The number of independent test variables were reduced to four: catalyst concentration, residence time, temperature, and air mass-flow rate.

Plant Description. – Figure 33 shows the flow diagrams for the phase II and IIa test units; both diagrams are shown to facilitate comparison. In the phase IIa process, effluent gas (an air-H_2S mixture) is separated from first aeration stage and recycled through the diffuser plates of a second stage in series. This flow regime promotes the dissolution and subsequent oxidation of much of the H_2S gas lost from the single-stage aeration process. The columns and associated equipment in the two-stage system are shown on figure 34.

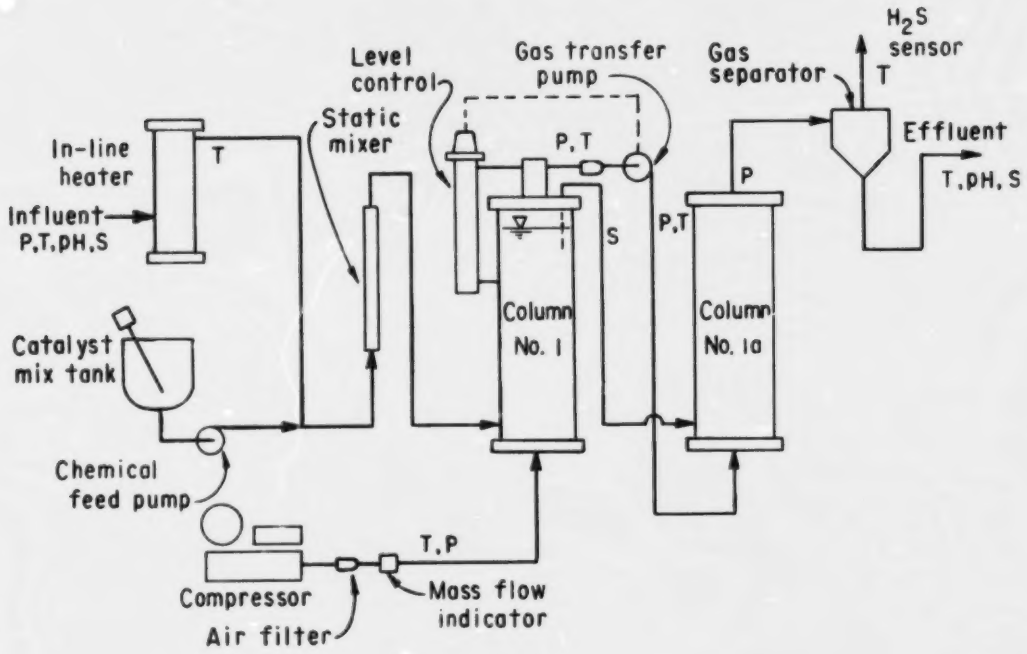
Gas transfer between stages was achieved using a gas transfer pump (compressor) and a displacer-operated level controller, as shown on figure 35. The brine level in the first stage was maintained at about 180 mm below the upper column flange to provide a gas volume for separation. Depending on the type of compressor used, the gas pumping rate was controlled using either a variable-speed drive or back-pressure valve. The level controller served as a high-level cutoff to prevent brine from being drawn into the compressor. A vapor trap was also placed upstream of the compressor to intercept any condensate.

Figure 32. – Diffuser plate assembly subsequent to phase II testing. P801-D-80941.

BEST COPY AVAILABLE



PHASE II



PHASE IIa

Figure 33. – Flow diagrams for phase II and IIa aeration units. Transducers are shown as pH, T (temperature), P (pressure), and S (sampling points).

BEST COPY AVAILABLE

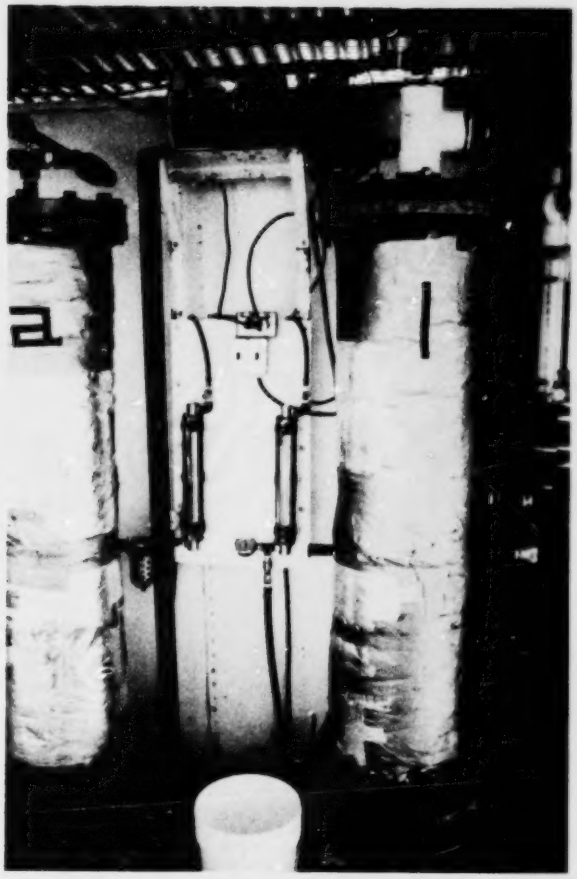


Figure 34. – Two-stage, gas recycle, aeration system for phase IIa. P801-D-80942.

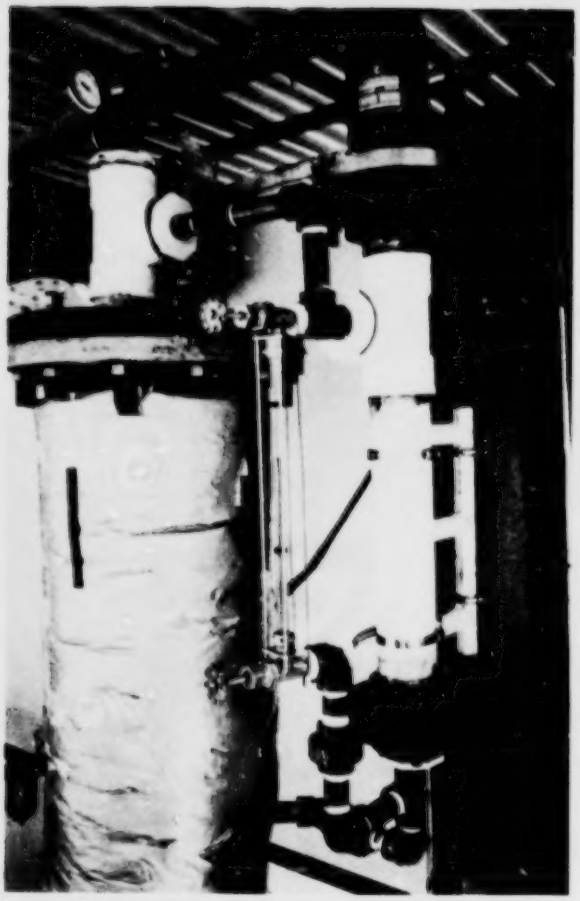


Figure 35. – First-stage aeration column and liquid-level controller. P801-D-80943.

Initially, interstage gas transfer was attempted using a positive-displacement piston compressor to achieve the required discharge pressure for injection into the second stage. Early problems were encountered with corrosion along the piston and cylinder walls from exposure to the high H_2S-water vapor environment. This resulted in the loss of discharge pressure and leakage of significant quantities of H_2S gas. We were able to complete the test runs using two diaphragm-type compressors, which eliminated gas leakage and were fairly resistant to the corrosive environment; however, compressor heating became a problem when back-pressuring for flow control.

The columns used were the same as those described for phase II. Liquid volume for both stages totaled 197 liters. A mean diffuser pore size of 49.5 μm, with a range from 44 to 55 μm, was used for all test runs. Otherwise, the equipment was as previously described for phase II testing.

Test Procedures. – A four-variable, Box-Behnken, experimental design was employed in this test phase. Associated independent variables $X_1 - X_4$, dependent variables $Y_1 - Y_6$, and independent variable test levels are presented in table 7. Table 8 lists the 27 runs required by the design. The details of this experimental approach and method of data analysis were discussed in previous phase II sections.

The operating range for each of the independent variables was maintained as close to the range used during phase II testing as possible to facilitate effluent data comparison. The test levels for variable X_2 (brine residence time) are somewhat higher because of the expanded system capacity and other equipment limitations. There is, however, an overlap between 15 and 25 minutes.

Table 7. — Phase IIa test variables and independent variable levels.

Variable	Description	Level			Units
		low	medium	high	
X_1	Catalyst concentration	1.0	5.0	9.0	mg/L of Ni^{+2}
X_2	Brine residence time	15	27.5	40	min
X_3	Brine feed temperature	16	20	24	°C
X_4	Air mass-flow rate	10	35	60	sL/min
Y_1	Interstage ΣS^{-2} concentration (filtered)				mg/L
Y_2	Effluent ΣS^{-2} concentration (unfiltered)				mg/L
Y_3	Effluent ΣS^{-2} concentration (filtered)				mg/L
Y_4	Interstage H_2S concentration				mg/m^3
Y_5	Effluent H_2S gas concentration				mg/m^3

As shown in table 7, ΣS^{-2} concentrations were measured in both effluent and interstage samples. The interstage analyses were primarily used for comparison with single-stage aeration results.

Results and Discussion. – Phase IIa test data are presented in table B-1 of appendix B. A total of 30 test runs were completed including 3 replicates (observations 1a through 3a). The data format is the same as that used in phase II.

As with the phase II results, effluent H_2S gas concentration measurements by the titrimetric (iodine) method of analysis were lower in phase IIa by an average of 38 percent than those obtained using the detector tubes. Again, there seems to be a uniform divergence with concentration of the two sets of data (fig. 25). Detector tube data were subsequently used in the regression analysis to assure conservative design equations.

The regression terms used in the data analyses are presented in table B-2 of appendix B. Variables X_{11} through X_{20} are transformations of the independent variables $X_1 - X_4$, which provide the remaining terms of the second degree polynomial. Seventeen higher order terms, $X_{21} - X_{37}$, were also included to take advantage of the software capacity. Variables X_{38} through X_{40} represent the percent ΣS^{-2} remaining in the effluent brine, effluent gas, and combined total, respectively. The complete data matrices for phase IIa are shown in table B-2 for the effluent data and table B-5 for the interstage data.

Table 9 presents a summary of results of four phase IIa regression analyses. Associated AOV tables and standardized residual plots are shown in appendix B in tables B-3, B-4, B-6, and B-7 and on figures B-1 and B-2, respectively. The statistical significance of the AOV information is discussed in the phase II results section. Correlation coefficients for the four regression equations were all fairly high, indicating little unexplained variance in the data. Based on the F-ratio values obtained, all regressions were shown to exhibit a significant fit at the 95-percent confidence interval.

Plots of the phase IIa regression equations are presented on figures 36 through 39. Figures 36 and 37 pertain to the interstage brine and gas data, and figures 38 and 39 pertain to the effluent brine and gas data, respectively. Each figure shows the effect on percent ΣS^{-2} removal of varying air mass-flow rate, catalyst concentration, resident time, and temperature at a fixed diffuser pore size. The effluent brine regression showed no temperature or catalyst concentration dependency; therefore, only three graphs were necessary to display the data on figure 38. As in phase II, the lines of equal H_2S concentration (mg/m^3 of S^{-2}) are superimposed over the 15 °C effluent gas plots. No back pressure was applied to the columns in this phase.

Discussion of the interstage data will be limited to the comment that, at equivalent variable levels, phase IIa interstage and phase II effluent regressions, both brine and gas, gave similar results as expected. This can be seen by comparing the 15 °C plots of figures 36 and 37 with the phase II results at the same temperature shown on figures 26 and 28, respectively. However, it should be noted that the comparison at 40 minutes residence time is not totally valid because of the extrapolation of phase II data outside of its experimental region.

As in phase II, air mass-flow rate X_4 and brine residence time X_2 were the two independent variables having the greatest impact on ΣS^{-2} removal in the effluent brine. In fact, in the phase IIa effluent brine analysis, they were the only test variables included in the regression; i.e., found to be significant at the 95-percent confidence interval. The positive effects

BEST COPY AVAILABLE

BEST COPY AVAILABLE

Table 8. -- Phase IIa expermental design.

Run No.	X_1				X_2		X_3	X_4
	Catalyst conc. (mg/L of Ni^{+2})	Batch conc. $NiSO_4 \cdot 6H_2O$ (g/L)	Feed rate (mL/min)	Pump setting at 78 strokes per min (%)	Residence time (min)	Influent flow rate (L/min)	Feed temp. (°C)	Diffused air mass-flow rate (sL/min)
1	5.0	0.505	550	76	15	13.2	16	35
2	5.0	.505	300	40	27.5	7.2	20	35
3	5.0	.505	204	29	40	4.9	24	35
4	1.0	.097	300	40	27.5	7.2	16	35
5	1.0	.097	300	40	27.5	7.2	20	60
6	1.0	.097	300	40	27.5	7.2	20	10
7	5.0	.505	204	29	40	4.9	16	35
8	5.0	.505	550	76	15	13.2	20	10
9	5.0	.505	300	40	27.5	7.2	20	35
10	9.0	.914	550	76	15	13.2	20	35
11	9.0	.914	204	29	40	4.9	20	35
12	9.0	.914	300	40	27.5	7.2	24	35
13	5.0	.505	300	40	27.5	7.2	16	10
14	5.0	.505	300	40	27.5	7.2	16	60
15	5.0	.505	300	40	27.5	7.2	24	60
16	1.0	.097	550	76	15	13.2	20	35
17	1.0	.097	204	29	40	4.9	20	35
18	1.0	.097	300	40	27.5	7.2	24	35
19	5.0	.505	204	29	40	4.9	20	60
20	5.0	.505	300	40	27.5	7.2	24	10
21	5.0	.505	550	76	15	13.2	20	60
22	9.0	.914	300	40	27.5	7.2	20	10
23	9.0	.914	300	40	27.5	7.2	16	35
24	9.0	.914	300	40	27.5	7.2	20	60
25	5.0	.505	204	29	40	4.9	20	10
26	5.0	.505	550	76	15	13.2	24	35
27	5.0	.505	300	40	27.5	7.2	20	35

Table 9. – Summary of phase IIa regression results.

	Correlation coefficient, percent	F-ratio value	Standard error, percent of ΣS^{-2}	Number of terms
Effluent brine	80.3	12.9	2.2	7
Effluent gas	92.5	32.5	0.6	8
Interstage brine	80.5	25.8	7.3	4
Interstage gas	89.5	22.4	2.1	8

Equations

Effluent brine:

$$Y = 84.880 - 3.964X_2 - 2.729X_4 + 0.110X_2X_4 + 0.045X_2^2 + 0.022X_4^2 - 0.001X_2^2X_4 - 0.001X_2X_4^2$$

Effluent gas:

$$Y = 18.555 - 0.425X_2 - 0.076X_1X_4 - 0.015X_3^2 + 0.001X_1X_2X_4 + 0.001X_1X_3X_4 + 0.001X_1^2X_4 + 0.0002X_2^2X_3 + 0.0002X_1X_4^2$$

Interstage brine:

$$Y = 60.882 - 0.863X_4 - 0.064X_3X_4 - 0.001X_1X_2X_4 + 0.001X_3X_4^2$$

Interstage gas:

$$Y = 29.559 - 0.934X_3 + 0.377X_4 - 0.112X_1X_4 - 0.004X_4^2 - 0.002X_1X_2X_4 + 0.007X_1^2X_3 + 0.001X_1X_2^2 + 0.002X_1X_4^2$$

of increasing catalyst concentration X_1 and temperature X_3 on total system oxidation are much more prevalent in the effluent gas results (fig. 39).

Two concerns were apparent regarding the phase IIa effluent plots. The first relatively minor concern was with the shape of the effluent brine curve (fig. 38) at 40 minutes residence, specifically with the ΣS^{-2} removal at the midlevel airflow compared to that attained at 27.5 minutes residence. The predicted removal at an airflow of 35 sL/min, when compared with actual data values, was found to be somewhat high. A slight downward adjustment based on these data points is shown by the dashed line.

The second concern was related to the curve reversal exhibited in the effluent gas plots (fig. 39) at the higher variable levels. Most probably, this is a manifestation of the polynomial expression to which the data were fit, as opposed to the actual data. The reversal is occurring, predominantly, at an extreme corner of the experimental region, at a point where no test run was made. Since a polynomial regression generally does not extrapolate well, it was concluded that the curve in this area may be deviating from a true fit solely due to its proximity to the experimental region boundary; i.e., unduly influenced by the curve outside the boundary.

Analysis of the phase IIa effluent data (tables B-1 and B-2, app. B) indicates more efficient oxidation using a second stage, with total sulfide removals exceeding 97 percent for several of the test runs. Of particular interest is the significant reduction in H_2S gas concentrations released from the system (7 of 30 runs below 50 mg/m³) compared to discharges during single-stage operation. The lowest recorded H_2S discharge with one stage was 301 mg/m³. Parametric data in both phases II and IIa have shown that oxidation efficiency improves with increasing temperature over an experimental range of 16 to 24 °C. It is important to realize that much of the data reflect operation at a temperature level in excess of that normally found at the wellhead (15.0 ± 0.5 °C). At operating temperatures between 16 and 17.3 °C, three test runs yielded effluent H_2S concentrations less than 100 mg/m³, which represent a significant improvement over single-stage operation.

Figures 40 and 41 present a comparison of the phase II and IIa regression results for filtered effluent

BEST COPY AVAILABLE

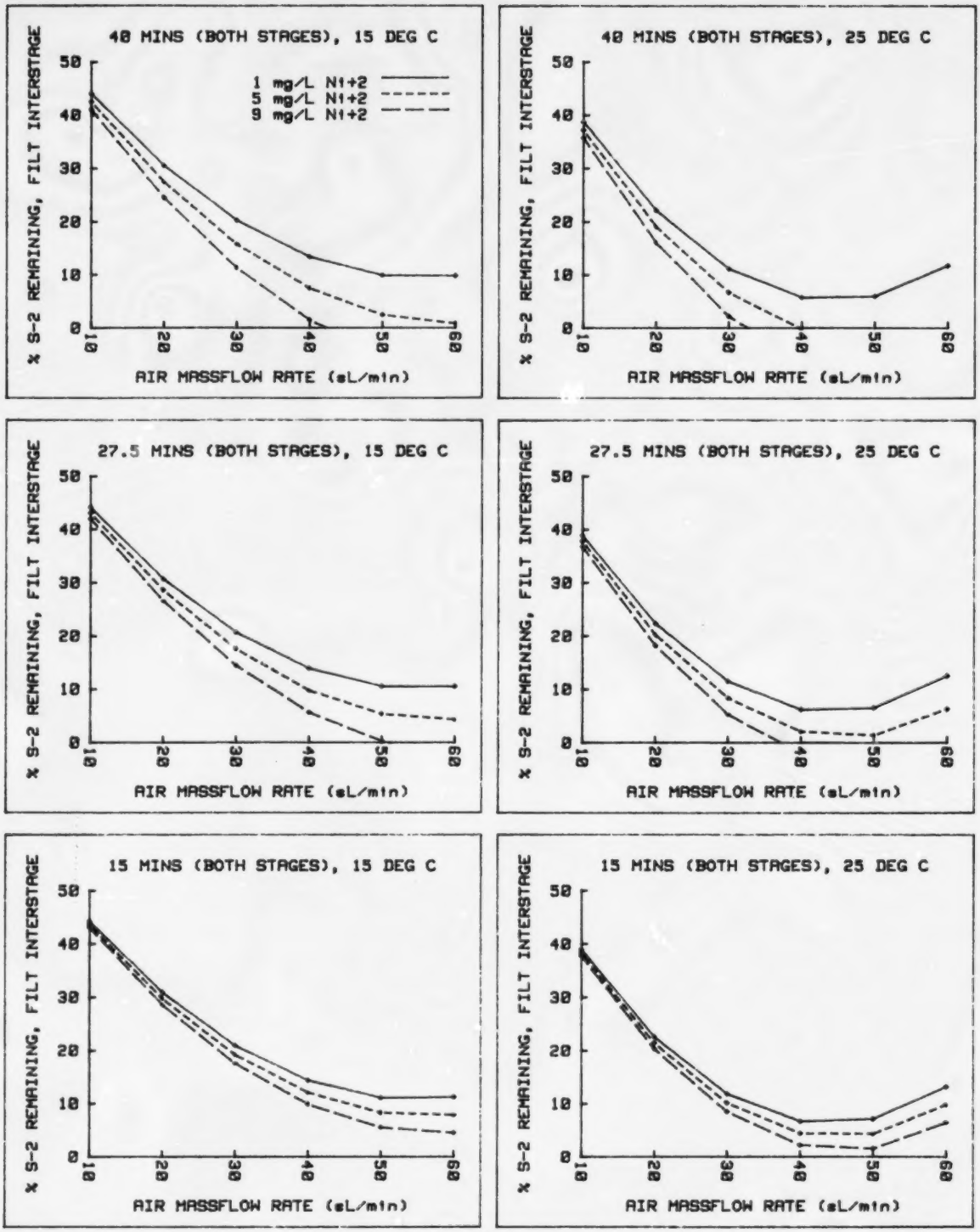

40 MINS (BOTH STAGES), 15 DEG C
1 mg/L Ni+2
5 mg/L Ni+2
9 mg/L Ni+2
% S-2 REMAINING, FILT INTERSTAGE
AIR MASSFLOW RATE (sL/min)
40 MINS (BOTH STAGES), 25 DEG C
% S-2 REMAINING, FILT INTERSTAGE
AIR MASSFLOW RATE (sL/min)
27.5 MINS (BOTH STAGES), 15 DEG C
% S-2 REMAINING, FILT INTERSTAGE
AIR MASSFLOW RATE (sL/min)
27.5 MINS (BOTH STAGES), 25 DEG C
% S-2 REMAINING, FILT INTERSTAGE
AIR MASSFLOW RATE (sL/min)
15 MINS (BOTH STAGES), 15 DEG C
% S-2 REMAINING, FILT INTERSTAGE
AIR MASSFLOW RATE (sL/min)
15 MINS (BOTH STAGES), 25 DEG C
% S-2 REMAINING, FILT INTERSTAGE
AIR MASSFLOW RATE (sL/min)

Figure 36. – Phase IIa interstage brine data.

BEST COPY AVAILABLE

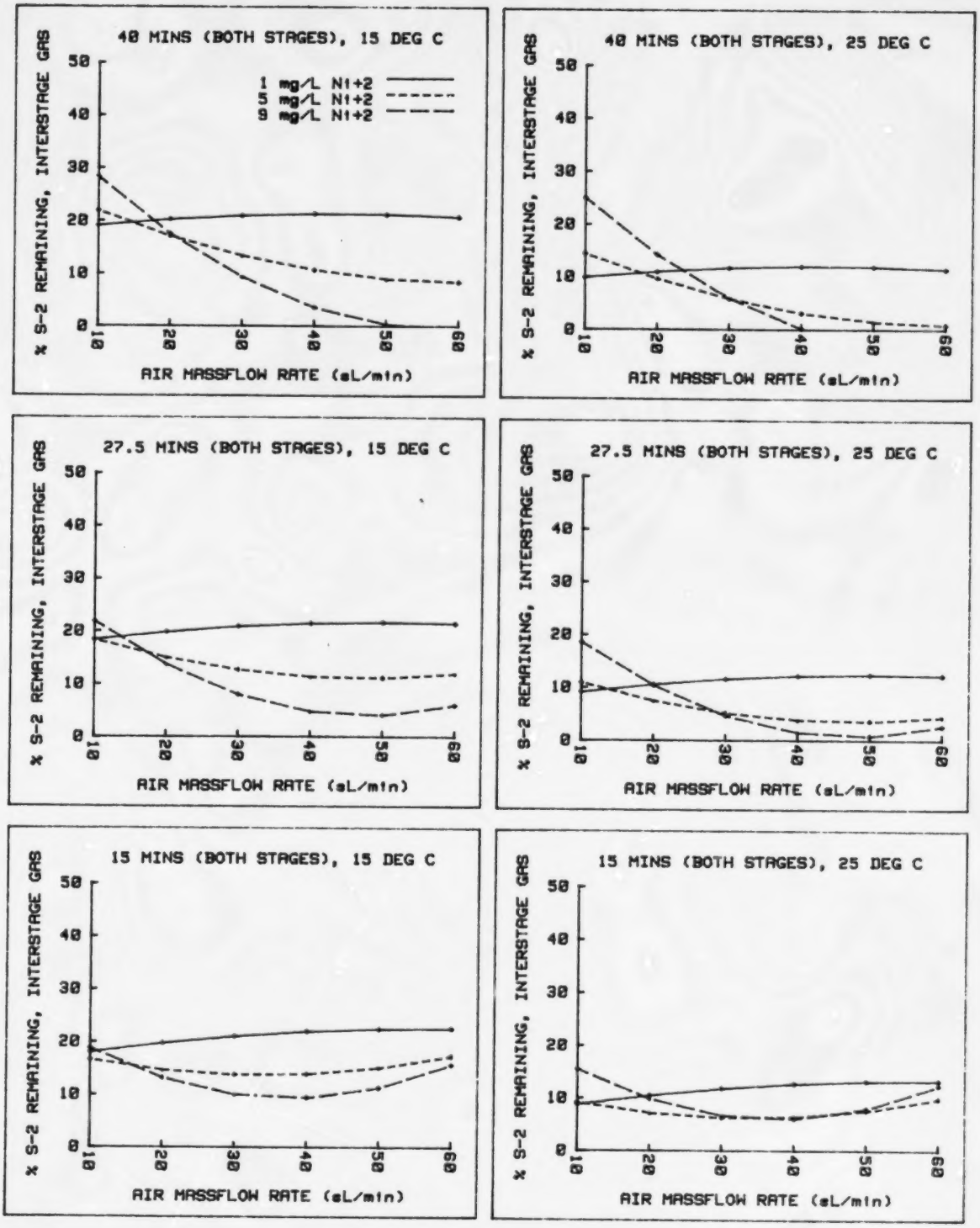

40 MINS (BOTH STAGES), 15 DEG C
1 mg/L Ni+2
5 mg/L Ni+2
9 mg/L Ni+2
% S-2 REMAINING, INTERSTAGE GAS
AIR MASSFLOW RATE (aL/min)
40 MINS (BOTH STAGES), 25 DEG C
% S-2 REMAINING, INTERSTAGE GAS
AIR MASSFLOW RATE (aL/min)
27.5 MINS (BOTH STAGES), 15 DEG C
% S-2 REMAINING, INTERSTAGE GAS
AIR MASSFLOW RATE (aL/min)
27.5 MINS (BOTH STAGES), 25 DEG C
% S-2 REMAINING, INTERSTAGE GAS
AIR MASSFLOW RATE (aL/min)
15 MINS (BOTH STAGES), 15 DEG C
% S-2 REMAINING, INTERSTAGE GAS
AIR MASSFLOW RATE (aL/min)
15 MINS (BOTH STAGES), 25 DEG C
% S-2 REMAINING, INTERSTAGE GAS
AIR MASSFLOW RATE (aL/min)

Figure 37. – Phase IIa interstage gas data.

BEST COPY AVAILABLE

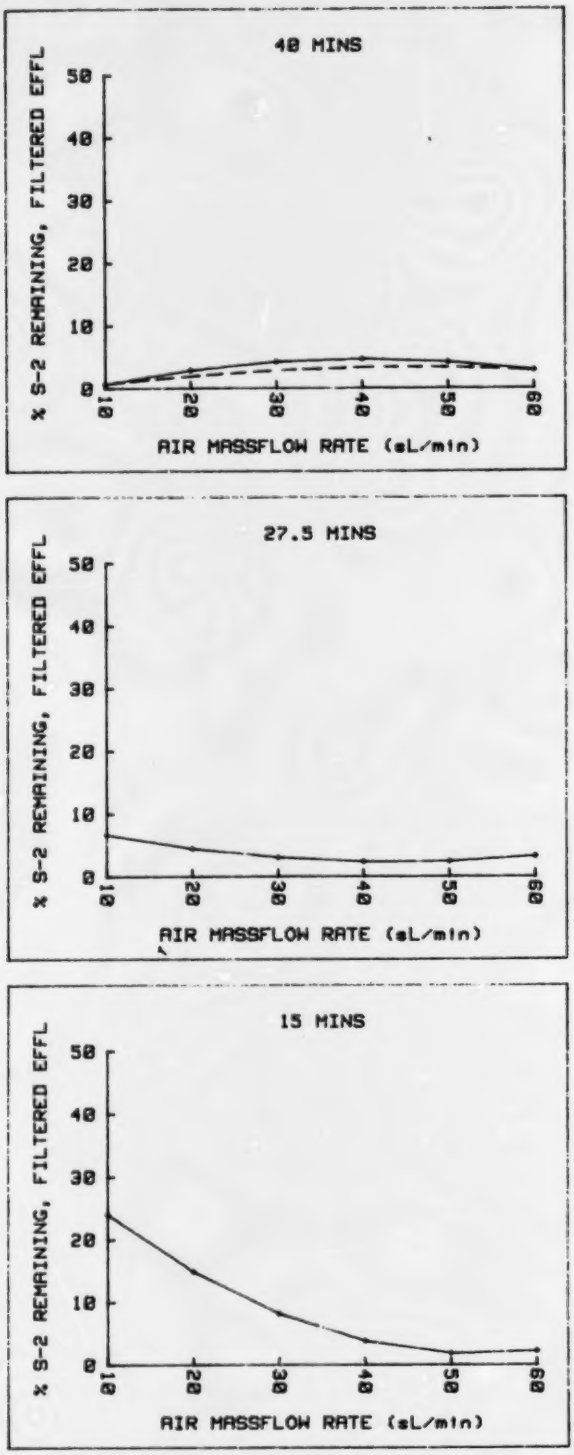


Figure 38. – Phase IIa effluent brine data. Varying the levels of temperature and catalyst concentration had no effect on this regression.

BEST COPY AVAILABLE

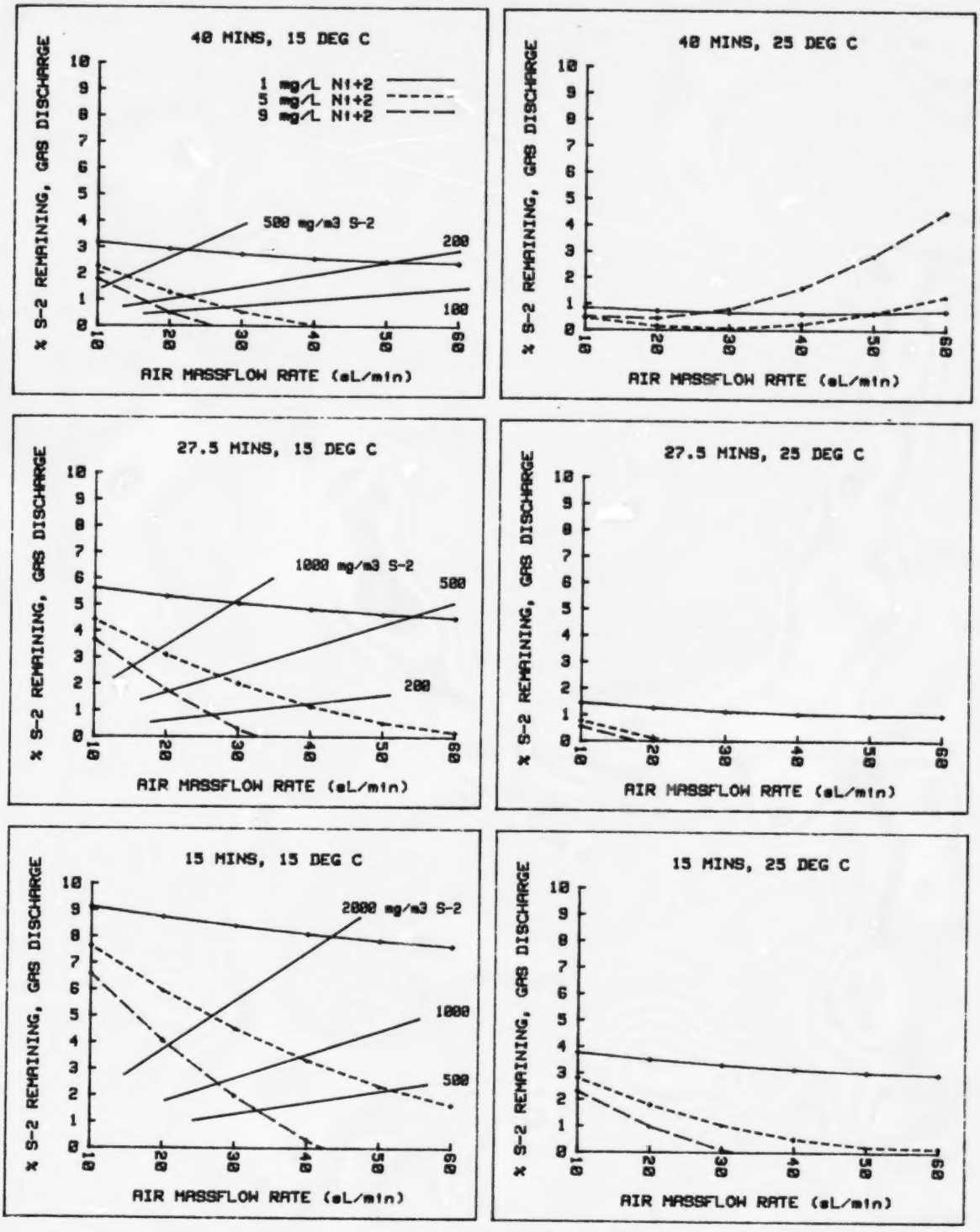
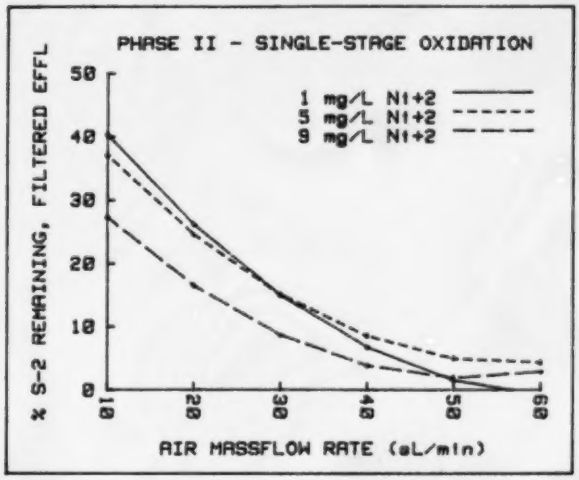
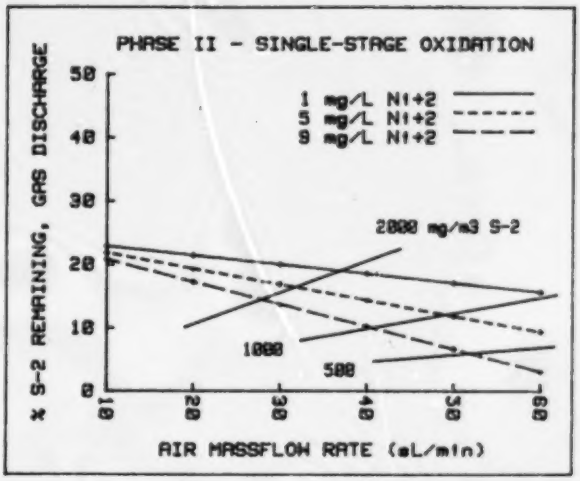
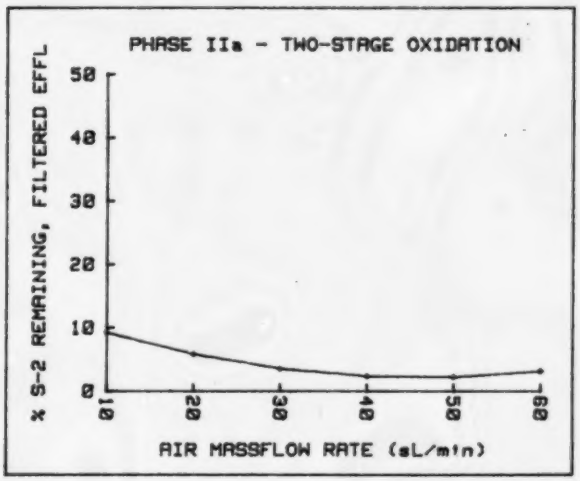


Figure 39. – Phase IIa effluent gas data.

BEST COPY AVAILABLE







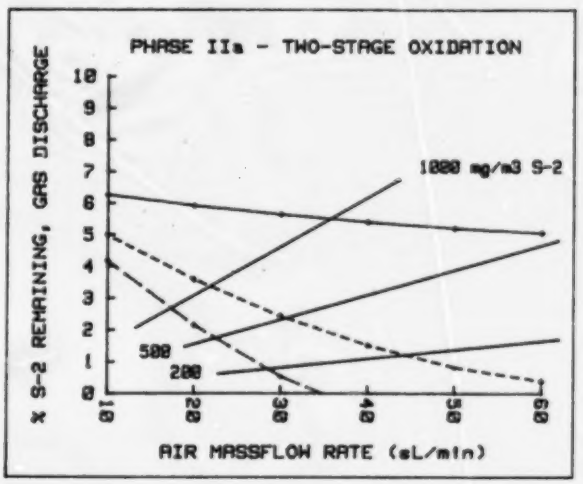


Figure 40. – Phases II and IIa effluent brine data comparison. Residence time of 25 minutes at 15 °C.

Figure 41. – Phases II and IIa effluent gas data comparison. Residence time of 25 minutes at 15 °C.

brine and gas, respectively, at a residence time of 25 minutes and temperature of 15 °C. Both figures show improved oxidation with the two-stage process. The difference is particularly noticeable on figure 41 when comparing sulfide concentrations attainable at selected catalyst concentrations and air mass-flow rates. For example, at 1 mg/L of Ni^{+2} and 60 sL/min air, the ΣS^{-2} removal is three times greater and the effluent H_2S concentration is two times less, 1000 and 500 mg/m³, respectively, for the two-stage aeration process. It also should be noted that influent brine flow at a given residence time in phase IIa was almost double that of phase II due to relative system capacities.

Postaeration Solids Removal

A series of laboratory scale tests were conducted to collect basic data regarding the removal of postaeration solids from Paradox brine. These included jar tests to screen various chemical coagulants and polymer aids, and centrifuge tests.

The chemical coagulants/flocculants screened during the jar testing included lime, $Ca(OH)_2$; ferric chloride, $FeCl_3$; alum, $Al_2(SO_4)_3 \cdot 14H_2O$; and five cationic polymers (Magnifloc). These chemicals were tested alone and in conjunction with three separate aids, a nonionic and two anionic polymers (Magnifloc). All polymers were evaluated throughout the dosage range recommended for the specific applications by the manufacturer. The most encouraging results were obtained using $FeCl_3$ without an aid. The polymer aids did not noticeably improve flocculation or settling rates. At 25 mg/L of $FeCl_3$ with 2-minute rapid mix (100 r/min) and 15-minute slow mix (20 r/min), supernatant turbidity readings averaged

BEST COPY AVAILABLE

about 25 NTU (Nephelometric Turbidity Units), as shown on figure 42. With subsequent filtration, turbidity values should drop well below 1.0 NTU. Floc formation was fairly large and complete within 5 to 8 minutes after rapid mix. Settling rates were difficult to establish because of the lack of a distinct interface; however, 5 minutes after termination of slow mix, most of the floc had completely settled (100 mm) with only a few scattered particles left in suspension. The settled floc was easily disturbed, which is characteristic of ferric hydroxide, $Fe(OH)_3$, precipitate.

Laboratory centrifuge tests were run on raw, aerated brine samples at centrifugal force, F_c, values of 9000, 25 000, and 32 000 (multiples of standard gravitation force) for durations of 5, 10, 15, and 20 minutes. Supernatant turbidity was used as a measure of solids removal effectiveness. The results, shown on figure 43, indicate fairly good removal, but only at the expense of either an extremely high F_c or high residence time. This approach was determined to be impractical.

Conclusions

The most significant conclusions drawn from this investigation are:

- Based on available test data, the nickle-catalyzed aeration process appears to be an effective method for oxidizing sulfide in Paradox brine. Total sulfide removals exceeded 90 percent for 16 of the 74 phase II (single-stage) parametric test runs, and 95 percent for 17 of the 30 phase IIa (two-stage) test runs.

- In single-stage testing, all observations where removals exceeded 90 percent were run at mid- or high-temperature levels. Thus, a 5 to 10 °C increase in brine temperature (above the wellhead temperature of 15.5 °C) was shown to significantly improve oxidation. This might suggest the application of a solar salt-gradient pond, constructed with Paradox brine, for preheating process influent. Thermal energy from a 6-hectare pond should be sufficient to raise the temperature of 56.6 L/s (2 ft^3/s) of saturated brine by 10 °C. This assumes a continuous pond thermal output of 40 W/m^2.

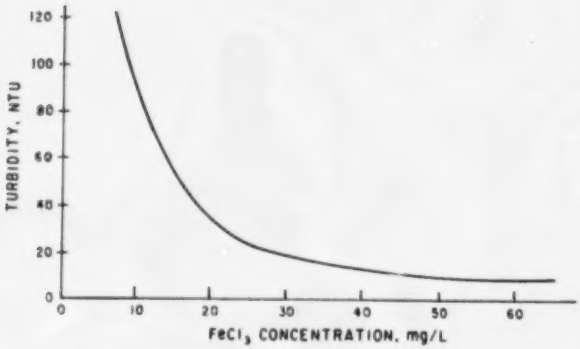


Figure 42. – Effluent turbidity as a function of $FeCl_3$ concentration for a 15-minute settling time.

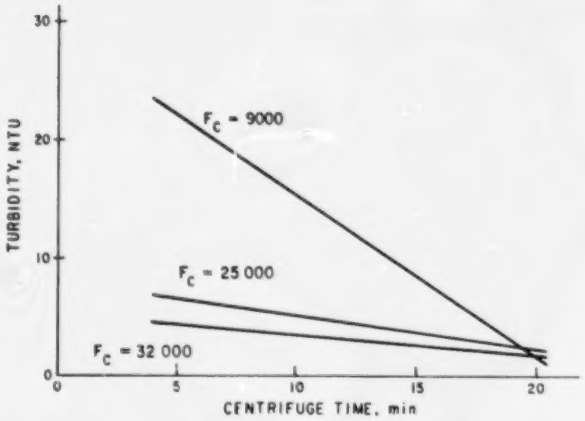


Figure 43. – Centrifuge test results on aerated brine samples.

- Phase IIa data indicate more efficient oxidation using a second aeration stage, with total sulfide removals exceeding 97 percent for several of the test runs. Of particular interest is the significant reduction in the H_2S gas concentrations released from the system (7 of 30 observations below 50 mg/m^3) compared to discharges during single-stage operation. The lowest recorded discharge with one stage was 301 mg/m^3. Also, there appears to be several good operating regions at 15 °C and at low catalyst levels with the two-stage process (figs. 38 and 39).

- The electrical energy required by the aeration process is very low compared to that required by the electrochemical process. For example, at similar brine pumping conditions, the energy consumed by the 10-hp compressor used to provide diffused air is about 0.13 Wh/L as compared to 2.90 Wh/L for the electrolytic cell, which equates to approximately a 23:1 ratio in electrical energy consumption.

- Diffuser fouling by precipitates formed in the oxidation reaction may be a potential problem in long-term operation. During parametric testing, there was a definite blackening of the diffuser surface from metal sulfide intermediates (fig. 32); however, no significant increase in head loss was noticed.

BEST COPY AVAILABLE

- $FeCl_3$ (ferric chloride) was found in jar tests to be the most effective coagulant, of several evaluated, for the removal of postaeration solids from Paradox brine. At 25 mg/L of $FeCl_3$ and 30 minutes combined mixing and settling time, supernatant turbidity readings averaged about 25 NTU. Polymer aids did not noticeably improve flocculation or settling rates.

RECOMMENDATIONS FOR FURTHER INVESTIGATION

Both the electrochemical oxidation and nickel-catalyzed aeration processes have been shown to be effective in removing sulfide from Paradox brine. However, because of the relatively high energy consumption of the former, it is the opinion of the authors that any future work be concentrated on further development of the aeration process, in the areas of improving O_2 transfer efficiency, avoiding the potential problems associated with diffuser fouling, and solids separation. Methods of improving oxygen transfer would include the use of a greater column depth, most probably in a single-stage system, and the investigation of different air diffuser types that are capable of producing significantly finer bubbles than were used in this study. As an example, one manufacturer has developed a diffuser that produces bubble diameters of about 0.1 mm by shearing off bubbles as they emerge from a rotating porous disk. It is estimated that bubbles of this size would increase the mass transfer surface area up to two orders of magnitude greater than achieved in the present work. Investigations relating to diffuser fouling would center on the use of diffusers that are less susceptible to fouling and the refining of operational procedures.

Another possible area of investigation would involve the testing of alternative, less expensive catalysts such as Fe^{+2}. Although Fe^{+2} has been shown not to be as active a catalyst as Ni^{+2}, as discussed earlier in the report, its use may prove to be more economical considering the overall process cost.

BIBLIOGRAPHY

[1] Chen, K. Y., and J. C. Morris, "Kinetics of Oxidation of Aqueous Sulfide by O_2," *Journal of Environmental Science and Technology*, vol. 6, No. 6, pp. 529-37, 1972.

[2] _____ "Oxidation of Sulfide by O_2: Catalyst and Inhibition," *Journal of the Sanitary Engineering Division*, Proceedings of American Society of Civil Engineers, pp. 215-27, February 1972.

[3] _____ "Oxidation of Aqueous Sulfide by O_2: General Characteristics and Catalytic Influences," *Advances in Water Pollution Research*, Proceedings of the Fifth International Conference, vol. 2, International Association on Water Pollution Research, Pergamon Press, 1970.

[4] Kaakinen, J. W., and W. F. Lorenz, "Report on Preliminary Bench Scale Tests of Several Hydrogen Sulfide Removal Methods for Paradox Valley Water," Bureau of Reclamation internal memorandum, September 1975.

[5] Boegli, W. J., and R. W. Schiller, *Pilot Plant Studies for the Removal of Hydrogen Sulfide–Paradox Valley Unit, Dolores River Project, Colorado: A Summary Report*, Bureau of Reclamation Report No. GR-10-77, Denver, CO, September 1977.

[6] E. I. DuPont de Nemours and Co., Inc., *Strategy of Experimentation*, DuPont Applied Technology Division, 1975.

[7] *Standard Methods for the Examination of Water and Wastewater*, 14th ed., p. 505, Method 428D, American Public Health Association, New York, NY, 1975.

[8] Perry, R. H., and C. H. Chilton, *Chemical Engineers' Handbook*, 5th ed., McGraw-Hill, New York, NY, 1973.

[9] Kumar, R., and N. R. Kuloor, "The Formation of Bubbles and Drops," *Advances in Chemical Engineering*, vol. 8, pp. 255-368, 1970.

BEST COPY AVAILABLE

APPENDIX A

Phase II Test Data

BEST COPY AVAILABLE

BLANK PAGE

Table A-1 – Phase II test data.

Run No.	X_1 Column press. (kPa)	X_2 Catalyst conc. (mg/L of Ni^{+2})	X_3 Residence time (min)	X_4 Column temp. (°C)	X_5 Average pore size (μm)	X_6 Air mass-flow rate (sL/min)	Influent ΣS^{-2} conc. (mg/L)	$Y_1(X_7)$ Filtered effluent ΣS^{-2} conc. (mg/L)	$Y_2(X_8)$ Effluent ΣS^{-2} conc. (mg/L)	$Y_3(X_9/X_{10})$ Effluent H_2S conc. (mg/m^3)*	pH Influent/ effluent
1	8.5	4.7	9.0	18.2	49.5	10.0	87.7	47.4	52.6	22 400/19 000	6.9/7.1
2	6.8	8.6	17.0	24.1	49.5	35.0	84.0	2.0	2.4	630/ 587	7.3/8.3
3	70.2	4.7	25.0	13.0	49.5	10.6	84.8	35.2	40.3	11 600/ 8 320	7.1/7.5
4	74.3	4.7	17.0	18.0	49.5	35.0	76.6	14.4	15.4	4 340/ 4 100	7.0/7.8
5	8.5	8.6	17.0	12.1	49.5	35.0	84.8	3.8	4.7	1 500/ 1 300	7.5/8.4
6	150.8	4.7	25.0	18.0	49.5	59.7	84.2	1.8	3.0	564/ 463	7.1/7.7
7	84.2	4.7	9.0	24.3	49.5	59.9	84.6	1.0	2.5	1 550/ 1 220	7.2/8.0
8	75.1	4.7	17.0	19.0	49.5	35.0	82.7	4.9	4.7	2 090/ 1 760	7.2/8.3
9	79.2	4.7	17.0	18.8	49.5	35.0	84.8	3.4	3.3	952/ 799	7.3/8.2
10	150.8	4.7	25.0	17.8	49.5	10.4	84.2	34.7	39.4	10 100/11 300	7.3/7.7
11	1.1	4.7	17.0	12.7	97.5	35.0	83.0	5.6	6.0	2 310/ 2 010	7.3/8.4
12	1.9	4.7	17.0	24.5	97.5	35.0	83.2	0.6	2.0	826/ 788	7.5/8.4
13	81.7	7.7	25.0	18.2	97.5	35.0	83.0	5.4	7.8	1 870/ 1 320	7.8/8.7
14	151.7	4.7	17.0	24.1	97.5	35.0	83.0	1.2	1.5	787/ 652	7.4/8.3
15	75.9	8.9	9.0	18.5	97.5	35.0	81.6	8.3	9.4	4 780/ 3 020	7.5/8.5
16	71.0	8.5	17.0	17.6	97.5	59.5	83.2	0.6	2.2	539/ 409	7.6/8.5
17	75.9	8.5	9.0	18.2	8.5	34.8	85.1	2.4	3.8	1 400/ 1 140	7.4/8.4
18	155.0	4.8	17.0	24.0	8.5	35.0	93.0	1.0	1.5	374/ 384	7.6/8.3
19	72.7	0.9	9.0	18.2	8.5	34.9	–	15.3	16.0	5 330/ 4 180	7.6/8.3
20	75.9	0.9	17.0	18.5	8.5	60.0	81.9	5.8	6.0	2 160/ 1 880	7.6/8.5
21	84.2	8.6	17.0	18.3	8.5	60.0	84.0	1.0	1.8	546/ 484	7.6/8.5
22	75.1	8.6	17.0	17.5	8.5	10.0	83.0	2.0	2.6	917/ 659	7.7/8.2
23	145.1	5.5	10.0	18.0	49.5	10.0	82.2	40.8	45.1	15 800/11 500	7.5/7.7
24	77.6	4.7	9.0	24.3	49.5	10.6	82.7	39.9	47.4	21 700/16 600	7.5/7.7
25	5.2	5.2	25.0	17.9	49.5	59.8	81.9	2.9	1.9	671/ 498	7.3/8.3
26	75.1	4.4	25.0	12.2	49.5	60.3	84.3	3.2	3.2	787/ 622	7.5/8.4
27	78.4	4.6	25.0	24.2	49.5	9.8	83.5	32.5	36.4	10 900/ 8 400	7.5/7.9
28	74.3	4.7	9.0	12.2	49.5	60.1	–	7.1	8.2	3 010/ 2 450	7.5/8.6
29	146.7	8.3	17.0	12.2	49.5	36.5	82.1	19.8	23.8	7 050/ 4 800	7.5/8.1
30	71.0	4.7	17.0	18.2	49.5	35.0	80.3	13.2	14.8	4 510/ 3 620	7.6/8.4

BEST COPY AVAILABLE

Table A-1 — Phase II test data.—Continued

Run No.	X_1 Column press. (kPa)	X_2 Catalyst conc. (mg/L of Ni^{+2})	X_3 Residence time (min)	X_4 Column temp. (°C)	X_5 Average pore size (μm)	X_6 Air mass-flow rate (sL/min)	Influent ΣS^{-2} conc. (mg/L)	$Y_1(X_7)$ Filtered effluent ΣS^{-2} conc. (mg/L)	$Y_2(X_8)$ Effluent ΣS^{-2} conc. (mg/L)	$Y_3(X_9/X_{10})$ Effluent H_2S conc. (mg/m^3)*	pH Influent/ effluent
31	150.0	4.9	9.0	18.5	49.5	60.3	83.5	5.9	6.6	3 180/ 1 960	7.6/8.6
32	18.3	4.7	9.0	18.2	49.5	60.1	83.7	4.3	4.6	2 670/ 2 060	7.5/8.6
33	67.7	8.6	17.0	17.7	97.5	10.6	82.9	33.3	38.9	16 200/13 000	7.5/7.8
34	136.0	4.7	17.0	12.3	97.5	36.6	84.0	22.5	22.2	4 360/ 4 170	7.6/8.2
35	77.6	0.9	9.0	18.9	97.5	35.1	84.3	16.6	18.6	6 320/ 4 620	7.5/8.4
36	76.8	0.9	17.0	17.6	97.5	10.0	82.7	41.4	48.6	16 200/14 100	7.7/7.9
37	72.7	0.9	17.0	17.6	97.5	60.0	83.5	8.2	7.7	2 160/ 1 850	7.6/8.5
38	80.1	0.9	25.0	18.5	97.5	35.3	83.7	4.1	4.4	1 660/ 1 270	7.6/8.3
39	78.4	0.9	17.0	17.8	8.5	9.7	85.3	12.2	12.4	5 080/ 4 090	7.6/8.3
40	80.1	0.9	25.0	18.5	8.5	36.5	84.2	4.6	5.6	1 740/ 1 180	7.7/8.4
41	9.3	4.7	17.0	24.3	8.5	35.0	85.0	2.9	3.7	995/ 715	7.6/8.5
42	9.3	4.7	17.0	11.9	8.5	35.1	85.1	21.6	22.0	5 740/ 4 540	7.7/8.5
43	81.7	8.3	25.0	18.4	8.5	35.3	84.0	7.2	8.4	1 830/ 1 310	7.7/8.7
44	151.7	4.6	17.0	11.9	8.5	34.6	83.4	23.1	25.4	5 280/ 4 [illegible]	7.6/8.4
45	149.2	1.0	17.0	23.3	49.5	34.9	82.2	19.4	23.0	4 420/ 4 570	7.6/8.4
46	8.5	1.0	17.0	23.5	49.5	35.5	82.1	5.8	6.2	2 810/ 2 930	7.6/8.5
47	7.6	1.0	17.0	12.1	49.5	35.2	82.4	14.2	16.5	3 850/ 3 870	7.6/8.5
48	159.1	1.0	17.0	11.8	49.5	35.0	83.2	23.3	27.0	5 280/ 4 810	7.6/8.3
49	150.0	8.3	17.0	24.4	49.5	34.7	83.0	3.5	5.8	1 830/ 1 120	7.6/8.6
50	80.9	4.6	25.0	24.5	49.5	60.5	83.5	2.6	2.7	367/ 375	8.0/8.5
51	82.5	4.7	9.0	12.2	49.5	10.8	85.1	45.8	51.9	19 800/15 600	7.5/7.8
52	77.6	4.5	17.0	18.8	49.5	35.2	83.0	11.0	11.3	2 770/ 2 210	7.3/8.4
53	80.1	4.7	17.0	18.2	49.5	35.0	82.4	7.4	7.4	2 070/ 1 530	7.4/8.5
54	2.7	5.1	25.0	18.6	49.5	10.1	84.5	30.2	34.4	11 700/ 8 260	7.7/8.1

BEST COPY AVAILABLE

50

Table A.1 – Phase II test data.–Continued

Run No.	X_1 Column press (kPa)	X_2 Catalyst conc. (mg/L of Ni^{+2})	X_3 Residence time (min)	X_4 Column temp. (°C)	X_5 Average pore size (μm)	X_6 Air mass-flow rate (sL/min)	Influent ΣS^{-2} conc. (mg/L)	$Y_1(X_7)$ Filtered effluent ΣS^{-2} conc. (mg/L)	$Y_2(X_8)$ Effluent ΣS^{-2} conc. (mg/L)	$Y_3(X_9/X_{10})$ Effluent H_2S conc. (mg/m^3)*	pH Influent/ effluent
1a	10.1	5.5	10.0	19.1	49.5	10.0	79.2	40.0	43.6	18 300/15 800	7.1/7.4
3a	79.2	4.3	23.2	14.5	49.5	10.0	86.2	33.6	42.4	10 200/ 7 350	7.1/7.4
6a	157.4	4.3	23.2	18.8	49.5	60.0	85.0	1.5	2.2	812/ 846	7.2/8.1
7a	81.7	5.5	10.0	24.5	49.5	60.0	82.7	1.4	1.6	1 100/ 1 030	7.2/8.1
10a	155.8	4.3	23.2	18.9	49.5	10.0	86.2	32.1	43.8	9 840/10 600	7.0/7.4
13a	75.1	7.6	23.2	18.5	97.5	34.7	83.0	1.0	1.6	301/ 353	7.5/8.3
13b	79.2	8.1	25.0	18.2	97.5	34.6	82.6	5.0	7.0	1 670/ 1 260	7.6/8.5
15a	75.1	10.0	10.0	18.2	97.5	35.0	84.0	3.8	3.3	2 170/ 1 700	7.5/8.4
15b	77.6	8.5	9.0	18.5	97.5	35.1	83.7	13.6	16.0	6 690/ 4 320	7.6/8.5
17a	77.6	10.0	10.0	18.8	8.5	35.0	81.9	1.2	1.8	930/ 847	7.6/8.4
19a	75.9	1.0	10.0	18.5	8.5	34.8	83.8	11.2	11.8	4 050/ 3 810	7.5/8.4
24a	72.7	5.5	10.0	24.1	49.5	10.0	81.4	38.4	45.4	20 100/16 100	7.6/7.8
25a	6.8	4.2	23.2	18.4	49.5	59.5	83.5	1.4	2.6	714/ 690	7.6/8.5
26a	74.3	4.2	23.2	12.7	49.5	60.0	83.4	3.0	3.3	714/ 638	7.6/8.4
27a	69.4	4.2	23.2	23.4	49.5	10.0	81.6	26.2	35.2	11 400/ 8 280	7.5/8.0
35a	80.9	0.9	9.0	18.4	97.5	34.7	82.7	19.0	20.2	6 850/ –	7.7/8.5
38a	82.5	0.9	25.0	17.9	97.5	34.6	83.8	4.0	3.8	1 720/ 1 210	7.7/8.5
53a	82.5	4.1	17.0	18.2	49.5	34.9	83.7	8.8	9.8	2 320/ 2 210	7.6/8.5
53b	76.8	4.6	17.0	17.9	49.5	35.1	83.9	7.9	9.3	2 520/ 1 890	7.3/8.5
53c	76.8	4.5	17.0	18.1	49.5	35.1	82.1	15.5	17.4	4 250/ 2 820	7.0/7.9

* Gastec detector tubes/titrimetric (iodine) method.

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix.

```
**********************************************************************
*                    BASIC STATISTICS AND DATA MANIPULATION          *
**********************************************************************
                          PARADOX PHASE II

Data file name: PVPH2:H8
Number of observations: 74
Number of variables: 40

Variables names:
   1. COL/M PRES
   2. CATL CONC
   3. RESID TIME
   4. COL/M TEMP
   5. PORE SIZE
   6. AIR MASSFL
   7. E FILT S-2
   8. E UNFL S-2
   9. E H2S GAST
  10. E H2S TITR
  11. E pH-I pH
  12. X1*X2
  13. X1*X3
  14. X1*X4
  15. X1*X5
  16. X1*X6
  17. X2*X3
  18. X2*X4
  19. X2*X5
  20. X2*X6
  21. X3*X4
  22. X3*X5
  23. X3*X6
  24. X4*X5
  25. X4*X6
  26. X5*X6
  27. X1^2
  28. X2^2
  29. X3^2
  30. X4^2
  31. X5^2
  32. X6^2
  33. X1*X4*X6
  34. X2*X3*X4
  35. X2*X3*X6
  36. X2*X4*X6
  37. X3*X4*X6
  38. % REM EFFL
  39. % REM GAS
  40. TOTL % REM

Subfiles:  NONE

                          PARADOX PHASE II

     Variable # 1   Variable # 2   Variable # 3   Variable # 4   Variable # 5
        Variable # 6   Variable # 7   Variable # 8   Variable # 9   Variable #10
     Variable #11   Variable #12   Variable #13   Variable #14   Variable #15
        Variable #16   Variable #17   Variable #18   Variable #19   Variable #20
     Variable #21   Variable #22   Variable #23   Variable #24   Variable #25
        Variable #26   Variable #27   Variable #28   Variable #29   Variable #30
     Variable #31   Variable #32   Variable #33   Variable #34   Variable #35
        Variable #36   Variable #37   Variable #38   Variable #39   Variable #40
OBS#
   1
        8.50000         4.70000         9.00000        18.20000        49.50000
          10.00000        47.40000        52.60000     22400.00000     19000.00000
           .20000        39.95000        76.50000       154.70000       420.75000
           85.00000        42.30000        85.54000       232.65000        47.00000
         163.80000       445.50000        90.00000       900.90000       182.00000
           495.00000        72.25000        22.09000        81.00000       331.24000
        2450.25000       100.00000      1547.00000       769.86000       423.00000
           855.40000      1638.00000        56.88000        17.40780        74.28780
   2
        6.80000         8.60000        17.00000        24.10000        49.50000
          35.00000         2.00000         2.40000       630.00000       587.00000
           1.00000        58.48000       115.60000       163.88000       336.60000
           238.00000       146.20000       207.26000       425.70000       301.00000
         409.70000       841.50000       595.00000      1192.95000       843.50000
           1732.50000        46.24000        73.96000       289.00000       580.81000
        2450.25000      1225.00000      5735.80000      3523.42000      5117.00000
           7254.10000     14339.50000         2.40000         3.55552         5.95552
```


BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

3

70.20000	4.70000	25.00000	13.00000	49.50000
10.60000	35.20000	40.30000	11600.00000	8320.00000
.40000	329.94000	1755.00000	912.60000	3474.90000
744.12000	117.50000	61.10000	232.65000	49.82000
325.00000	1237.50000	265.00000	643.50000	137.80000
524.70000	4928.04000	22.09000	625.00000	169.00000
2450.25000	112.36000	9673.56000	1527.50000	1245.50000
647.66000	3445.00000	42.24000	22.44486	64.68486

4

74.30000	4.70000	17.00000	18.00000	49.50000
35.00000	14.40000	15.40000	4340.00000	4100.00000
.60000	349.21000	1263.10000	1337.40000	3677.85000
2600.50000	79.90000	84.60000	232.65000	164.50000
306.00000	841.50000	595.00000	891.00000	630.00000
1732.50000	5520.49000	22.09000	289.00000	324.00000
2450.25000	1225.00000	46809.00000	1438.20000	2796.50000
2961.00000	10710.00000	17.28000	24.83411	42.11411

5

8.50000	8.60000	17.00000	12.10000	49.50000
35.00000	3.80000	4.70000	1500.00000	1300.00000
.90000	73.10000	144.50000	102.85000	420.75000
297.50000	146.20000	104.06000	425.70000	301.00000
205.70000	841.50000	595.00000	598.95000	423.50000
1732.50000	72.25000	73.96000	289.00000	146.41000
2450.25000	1225.00000	3599.75000	1769.02000	5117.00000
3642.10000	7199.50000	4.56000	7.87423	12.43423

6

150.80000	4.70000	25.00000	18.00000	49.50000
59.70000	1.80000	3.00000	564.00000	463.00000
.60000	708.76000	3770.00000	2714.40000	7464.60000
9002.76000	117.50000	84.60000	232.65000	280.59000
450.00000	1237.50000	1492.50000	891.00000	1074.60000
2955.15000	22740.64000	22.09000	625.00000	324.00030
2450.25000	3564.09000	162049.68000	2115.00000	7014.75000
5050.62000	26865.00000	2.16000	7.03466	9.19466

7

84.20000	4.70000	9.00000	24.30000	49.50000
59.90000	1.00000	2.50000	1550.00000	1220.00000
.80000	395.74000	757.80000	2046.06000	4167.90000
5043.58000	42.30000	114.21000	232.65000	281.53000
218.70000	445.50000	539.10000	1202.85000	1455.57000
2965.05000	7089.64000	22.09000	81.00000	590.49000
2450.25000	3588.01000	122558.99400	1027.89000	2533.77000
6841.17900	13100.13000	1.20000	6.69541	7.89541

8

75.10000	4.70000	17.00000	19.00000	49.50000
35.00000	4.90000	4.70000	2090.00000	1760.00000
1.10000	352.97000	1276.70000	1426.90000	3717.45000
2628.50000	79.90000	89.30000	232.65000	164.50000
323.00000	841.50000	595.00000	940.50000	665.00000
1732.50000	5640.01000	22.09000	289.00000	361.00000
2450.25000	1225.00000	49941.50000	1518.10000	2796.50000
3125.50000	11305.00000	5.88000	10.66050	16.54050

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

9

79.20000	4.70000	17.00000	18.80000	49.50000
35.00000	3.40000	3.30000	952.00000	799.00000
.90000	372.24000	1346.40000	1488.96000	3920.40000
2772.00000	79.90000	88.36000	232.65000	164.50000
319.60000	841.50000	595.00000	930.60000	658.00000
1732.50000	6272.64000	22.09000	289.00000	353.44000
2450.25000	1225.00000	52113.60000	1502.12000	2796.50000
3092.60000	11186.00000	4.08000	4.83962	8.91962

10

150.90000	4.70000	25.00000	17.80000	49.50000
10.40000	34.70000	39.40000	10100.00000	11300.00000
.40000	708.76000	3770.00000	2684.24000	7464.60000
1568.32000	117.50000	83.66000	232.65000	48.88000
445.00000	1237.50000	260.00000	881.10000	185.12000
514.80000	22740.64000	22.09000	625.00000	316.84000
2450.25000	108.16000	27916.09600	2091.50000	1222.00000
870.06400	4628.00000	41.64000	29.90884	71.54884

11

1.10000	4.70000	17.00000	12.70000	97.50000
35.00000	5.60000	6.00000	2310.00000	2010.00000
1.10000	5.17000	18.70000	13.97000	107.25000
38.50000	79.90000	59.69000	458.25000	164.50000
215.90000	1657.50000	595.00000	1238.25000	444.50000
3412.50000	1.21000	22.09000	289.00000	161.29000
9506.25000	1225.00000	488.95000	1014.73000	2796.50000
2089.15000	7556.50000	6.72000	12.17477	18.89477

12

1.90000	4.70000	17.00000	24.50000	97.50000
35.00000	.60000	2.00000	826.00000	788.00000
.90000	8.93000	32.30000	46.55000	185.25000
66.50000	79.90000	115.15000	458.25000	164.50000
416.50000	1657.50000	595.00000	2383.75000	857.50000
3412.50000	3.61000	22.09000	289.00000	600.25000
9506.25000	1225.00000	1629.25000	1957.55000	2796.50000
4030.25000	14577.50000	.72000	4.77299	5.49299

13

81.70000	7.70000	25.00000	18.20000	97.50000
35.00000	5.40000	7.80000	1870.00000	1320.00000
.90000	629.09000	2042.50000	1486.94000	7965.75000
2859.50000	192.50000	140.14000	750.75000	269.50000
455.00000	2437.50000	875.00000	1774.50000	637.00000
3412.50000	6674.89000	59.29000	625.00000	331.24000
9506.25000	1225.00000	52042.90000	3503.50000	6737.50000
4904.90000	15925.00000	6.48000	11.75790	18.23790

14

151.70000	4.70000	17.00000	24.10000	97.50000
35.00000	1.20000	1.50000	787.00000	652.00000
.90000	712.99000	2578.90000	3655.97000	14790.75000
5309.50000	79.90000	113.27000	458.25000	164.50000
409.70000	1657.50000	595.00000	2349.75000	843.50000
3412.50000	23012.89000	22.09000	289.00000	580.81000
9506.25000	1225.00000	127958.95000	1925.59000	2796.50000
3964.45000	14339.50000	1.44000	3.94923	5.38923

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

15

75.90000	8.90000	9.00000	18.50000	97.50000
35.00000	8.30000	9.40000	4780.00000	3020.00000
1.00000	675.51000	683.10000	1404.15000	7400.25000
2656.50000	80.10000	164.65000	867.75000	311.50000
166.50000	877.50000	315.00000	1803.75000	647.50000
3412.50000	5760.81000	79.21000	81.00000	342.25000
9506.25000	1225.00000	49145.25000	1481.85000	2803.50000
5762.75000	5827.50000	9.96000	9.68423	19.64423

16

71.00000	3.50000	17.00000	17.60000	97.50000
59.50000	.60000	2.20000	539.00000	409.00000
.90000	603.50000	1207.00000	1249.60000	6922.50000
4224.50000	144.50000	149.60000	828.75000	505.75000
299.20000	1657.50000	1011.50000	1716.00000	1047.20000
5801.25000	5041.00000	72.25000	289.00000	309.76000
3506.25000	3540.25000	74351.20000	2543.20000	8597.75000
8901.20000	17802.40000	.72000	4.21150	4.93150

17

75.90000	8.50000	9.00000	18.20000	8.50000
34.80000	2.40000	3.80000	1400.00000	1140.00000
1.00000	645.15000	683.10000	1381.38000	645.15000
2641.32000	76.50000	154.70000	72.25000	295.80000
163.80000	76.50000	313.20000	154.70000	633.36000
295.80000	5760.81000	72.25000	81.00000	331.24000
72.25000	1211.04000	48072.02400	1392.30000	2662.20000
5383.56000	5700.24000	2.88000	3.63475	6.51475

18

155.00000	4.80000	17.00000	24.00000	8.50000
35.00000	1.00000	1.50000	374.00000	384.00000
.70000	744.00000	2635.00000	3720.00000	1317.50000
5425.00000	81.60000	115.20000	40.80000	168.00000
408.00000	144.50000	595.00000	204.00000	840.00000
297.50000	24025.00000	23.04000	289.00000	576.00000
72.25000	1225.00000	130200.00000	1958.40000	2856.00000
4032.00000	14280.00000	1.20000	2.32593	3.52593

19

72.70000	.90000	9.00000	18.20000	8.50000
34.90000	15.30000	16.00000	5330.00000	4180.00000
.70000	65.43000	654.30000	1323.14000	617.95000
2537.23000	8.10000	16.38000	7.65000	31.41000
163.80000	76.50000	314.10000	154.70000	635.18000
296.65000	5285.29000	.81000	81.00000	331.24000
72.25000	1218.01000	46177.58600	147.42000	282.69000
571.66200	5716.62000	18.36000	13.36571	31.72571

20

75.90000	.90000	17.00000	18.50000	8.50000
60.00000	5.80000	6.00000	2160.00000	1830.00000
.90000	68.31000	1290.30000	1404.15000	645.15000
4554.00000	15.30000	16.65000	7.65000	54.00000
314.50000	144.50000	1020.00000	157.25000	1110.00000
510.00000	5760.81000	.81000	289.00000	342.25000
72.25000	3600.00000	84249.00000	283.05000	918.00000
999.00000	18870.00000	6.96000	19.52117	26.48117

BEST COPY AVAILABLE

Table A-2. – Phase II transformed variable listing and data matrix. – Continued

21

84.20000	8.60000	17.00000	18.30000	8.50000
60.00000	1.00000	1.80000	546.00000	484.00000
.90000	724.12000	1431.40000	1540.86000	715.70000
5052.00000	146.20000	157.38000	73.10000	516.00000
311.10000	144.50000	1020.00000	155.55000	1098.00000
510.00000	7089.64000	73.96000	289.00000	334.89000
72.25000	3600.00000	92451.60000	2675.46000	8772.00000
9442.80000	18666.00000	1.20000	5.02566	6.22566

22

75.10000	8.60000	17.00000	17.50000	8.50000
10.00000	2.00000	2.60000	917.00000	659.00000
.50000	645.86000	1276.70000	1314.25000	638.35000
751.00000	146.20000	150.50000	73.10000	86.00000
297.50000	144.50000	170.00000	148.75000	175.00000
85.00000	5640.01000	73.96000	289.00000	306.25000
72.25000	100.00000	13142.50000	2558.50000	1462.00000
1505.00000	2975.00000	2.40000	1.14047	3.54047

23

145.10000	5.50000	10.00000	18.00000	49.50000
10.00000	40.80000	45.10000	15800.00000	11500.00000
.20000	798.05000	1451.00000	2611.80000	7182.45000
1451.00000	55.00000	99.00000	272.25000	55.00000
180.00000	495.00000	100.00000	891.00000	180.00000
495.00000	21054.01000	30.25000	100.00000	324.00000
2450.25000	100.00000	26118.00000	990.00000	550.00000
990.00000	1800.00000	48.96000	11.70700	60.66700

24

77.60000	4.70000	9.00000	24.30000	49.50000
10.60000	39.90000	47.40000	21700.00000	16600.00000
.20000	364.72000	698.40000	1885.68000	3841.20000
822.56000	42.30000	114.21000	232.65000	49.82000
218.70000	445.50000	95.40000	1202.85000	257.58000
524.70000	6021.76000	22.09000	81.00000	590.49000
2450.25000	112.36000	19988.20800	1027.89000	448.38000
1210.62600	2318.22000	47.88000	16.12146	64.00146

25

5.20000	5.20000	25.00000	17.90000	49.50000
59.80000	2.90000	1.90000	671.00000	498.00000
1.00000	27.04000	130.00000	93.08000	257.40000
310.96000	130.00000	93.08000	257.40000	310.96000
447.50000	1237.50000	1495.00000	886.05000	1070.42000
2960.10000	27.04000	27.04000	625.00000	320.41000
2450.25000	3576.04000	5566.18400	2327.00000	7774.00000
5566.18400	26760.50000	3.48000	7.57911	11.05911

26

75.10000	4.40000	25.00000	12.20000	49.50000
60.30000	3.20000	3.20000	787.00000	622.00000
.90000	330.44000	1877.50000	916.22000	3717.45000
4528.53000	110.00000	53.68000	217.80000	265.32000
305.00000	1237.50000	1507.50000	603.90000	735.66000
2984.85000	5640.01000	19.36000	625.00000	148.84000
2450.25000	3636.09000	55248.06600	1342.00000	6633.00000
3236.90400	18391.50000	3.84000	9.54543	13.38543

BEST COPY AVAILABLE

Table A-2. – Phase II transformed variable listing and data matrix. – Continued

27

78.40000	4.60000	25.00000	24.20000	49.50000
9.80000	32.50000	36.40000	10900.00000	8400.00000
.40000	360.64000	1960.00000	1897.28000	3880.80000
768.32000	115.00000	111.32000	227.70000	45.08000
605.00000	1237.50000	245.00000	1197.90000	237.16000
485.10000	6146.56000	21.16000	625.00000	585.64000
2450.25000	96.04000	18593.34400	2783.00000	1127.00000
1090.93600	5929.00000	39.00000	20.95044	59.95044

28

74.30000	4.70000	9.00000	12.20000	49.50000
60.10000	7.10000	8.20000	3010.00000	2450.00000
1.10000	349.21000	668.70000	906.46000	3677.85000
4465.43000	42.30000	57.34000	232.65000	282.47000
109.80000	445.50000	540.90000	603.90000	733.22000
2974.95000	5520.49000	22.09000	81.00000	148.84000
2450.25000	3612.01000	54478.24600	516.06000	2542.23000
3446.13400	6598.98000	8.52000	13.49059	22.01059

29

146.70000	8.30000	17.00000	12.20000	49.50000
36.50000	19.80000	23.80000	7050.00000	4800.00000
.60000	1217.61000	2493.90000	1789.74000	7261.65000
5354.55000	141.10000	101.26000	410.85000	302.95000
207.40000	841.50000	620.50000	603.90000	445.30030
1806.75000	21520.89000	68.89000	289.00000	148.84000
2450.25000	1332.25000	65325.51000	1721.42000	5150.15000
3695.99000	7570.10000	20.76000	30.32011	54.08011

30

71.00000	4.70000	17.00000	18.20000	49.50000
35.00000	13.20000	14.80000	4510.00000	3629.00000
.80000	333.70000	1207.00000	1292.20000	3514.50000
2485.00000	79.90000	85.54000	232.65000	164.50000
309.40000	841.50000	595.00000	900.90000	637.00000
1732.50000	5041.00000	22.09000	289.00000	331.24000
2450.25000	1225.00000	45227.00000	1454.18000	2795.50000
2993.90000	10829.00000	15.84000	21.92670	37.76670

31

150.00000	4.90000	9.00000	18.50000	49.50000
60.30000	5.90000	6.60000	3180.00000	1960.00000
1.00000	735.00000	1350.00000	2775.00000	7425.00000
9045.00000	44.10000	90.65000	242.55000	295.47000
166.50000	445.50000	542.70000	915.75000	1115.55000
2984.85000	22500.00000	24.01000	81.00000	342.25000
2450.25000	3636.09000	167332.50000	815.85000	2659.23000
5466.19500	10039.95000	7.08000	10.82838	17.90838

32

18.30000	4.70000	9.00000	18.20000	49.50000
60.10000	4.30000	4.60000	2670.00000	2060.00000
1.10000	86.01000	164.70000	333.06000	905.85000
1099.83000	42.30000	85.54000	232.65000	282.47000
163.80000	445.50000	540.90000	900.90000	1093.82000
2974.95000	334.89000	22.09000	81.00000	331.24000
2450.25000	3612.01000	20016.90600	769.86000	2542.23000
5140.95400	9844.38000	5.16000	11.34311	16.50311

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

33

67.70000	8.60000	17.00000	17.70000	97.50000
10.60000	33.30000	38.90000	16200.00000	13000.00000
.30000	582.22000	1150.90000	1198.29000	6600.75000
717.62000	146.20000	152.22000	838.50000	91.16000
300.90000	1657.50000	180.20000	1725.75000	187.62000
1033.50000	4583.29000	73.96000	289.00000	313.29000
9506.25000	112.36000	12701.87400	2587.74000	1549.72000
1613.53200	3189.54000	39.96000	23.84767	63.80767

34

136.00000	4.70000	17.00000	12.30000	97.50000
36.60000	22.50000	22.20000	4360.00000	4170.00000
.60000	639.20000	2312.00000	1672.80000	13260.00000
4977.60000	79.90000	57.81000	458.25000	172.02000
209.10000	1657.50000	622.20000	1199.25000	450.18000
3568.50000	18496.00000	22.09000	289.00000	151.29000
9506.25000	1339.56000	61224.48000	982.77000	2924.34000
2115.84600	7653.06000	27.00000	26.41276	53.41276

35

77.60000	.90000	9.00000	18.90000	97.50000
35.10000	16.60000	18.60000	6320.00000	4620.00000
.90000	69.84000	698.40000	1466.64000	7566.00000
2723.76000	8.10000	17.01000	87.75000	31.59000
170.10000	877.50000	315.90000	1842.75000	663.39000
3422.25000	6021.76000	.81000	81.00000	357.21000
9506.25000	1232.01000	51479.06400	153.09000	284.31000
597.05100	5970.51000	19.92000	14.85728	34.77728

36

76.80000	.90000	17.00000	17.60000	97.50000
10.00000	41.40000	48.60000	16200.00000	14100.00000
.20000	69.12000	1305.60000	1351.68000	7488.00000
768.00000	15.30000	15.84000	87.75000	9.00000
299.20000	1657.50000	170.00000	1716.00000	176.00000
975.00000	5898.24000	.81000	289.00000	309.76000
9506.25000	100.00000	13516.80000	269.28000	153.00000
158.40000	2992.00000	49.68000	24.40146	74.08146

37

72.70000	.90000	17.00000	17.60000	97.50000
60.00000	8.20000	7.70000	2160.00000	1850.00000
.90000	65.43000	1235.90000	1279.52000	7088.25000
4362.00000	15.30000	15.84000	87.75000	54.00000
299.20000	1657.50000	1020.00000	1716.00000	1056.00000
5850.00000	5285.29000	.81000	289.00000	309.76000
9506.25000	3600.00000	76771.20000	269.28000	918.00000
950.40000	17952.00000	9.84000	19.20966	29.04966

38

80.10000	.90000	25.00000	18.50000	97.50000
35.30000	4.10000	4.40000	1660.00000	1270.00000
.70000	72.09000	2002.50000	1481.85000	7809.75000
2827.53000	22.50000	16.65000	87.75000	31.77000
462.50000	2437.50000	882.50000	1803.75000	653.05000
3441.75000	6416.01000	.81000	625.00000	342.25000
9506.25000	1246.09000	52309.30500	416.25000	794.25000
587.7450	16326.25000	4.92000	11.40949	16.32949

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

39

78.40000	.90000	17.00000	17.80000	8.50000
9.70000	12.20000	12.40000	5080.00000	4090.00000
.70000	70.56000	1332.80000	1395.52000	666.40000
760.48000	15.30000	16.02000	7.65000	8.73000
302.60000	144.50000	164.90000	151.30000	172.66000
82.45000	6146.56000	.81000	289.00000	316.84000
72.25000	94.09000	13536.54400	272.34000	148.41000
155.39400	2935.22000	14.64000	6.86581	21.50581

40

80.10000	.90000	25.00000	18.50000	8.50000
36.50000	4.60000	5.60000	1740.00000	1180.00000
.70000	72.09000	2002.50000	1481.85000	680.85000
2923.65000	22.50000	16.65000	7.65000	32.85000
462.50000	212.50000	912.50000	157.25000	675.25000
310.25000	6416.01000	.81000	625.00000	342.25000
72.25000	1332.25000	54087.52500	416.25000	821.25000
607.72500	16881.25000	5.52000	10.96132	16.48132

41

9.30000	4.70000	17.00000	24.30000	8.50000
35.00000	2.90000	3.70000	995.00000	715.00000
.90000	43.71000	158.10000	225.99000	79.05000
325.50000	79.90000	114.21000	39.95000	164.50000
413.10000	144.50000	595.00000	206.55000	850.50000
297.50000	86.49000	22.09000	289.00000	590.49000
72.25000	1225.60000	7909.65000	1941.57000	2796.50000
3997.35000	14458.50000	3.48000	4.33083	7.81083

42

9.30000	4.70000	17.00000	11.90000	8.50000
35.10000	21.60000	22.00000	5740.00000	4540.00000
.80000	43.71000	158.10000	110.67000	79.05000
326.43000	79.90000	55.93000	39.95000	164.97000
202.30000	144.50000	596.70000	101.15000	417.69000
298.35000	86.49000	22.09000	289.00000	141.61000
72.25000	1232.01000	3884.51700	950.81000	2804.49000
1963.14300	7100.73000	25.92000	27.57780	53.49780

43

81.70000	8.30000	25.00000	18.40000	8.50000
35.30000	7.20000	8.40000	1830.00000	1310.00000
1.00000	678.11000	2042.50000	1503.28000	694.45000
2884.01000	207.50000	152.72000	70.55000	292.99000
460.00000	212.50000	882.50000	156.40000	649.52000
300.05000	6674.89000	68.89000	625.00000	338.56000
72.25000	1246.09000	53065.78400	3818.00000	7324.75600
5391.01600	16233.00000	9.64000	11.76884	20.40884

44

151.70000	4.60000	17.00000	11.90000	8.50000
34.60000	23.10000	25.40000	5280.00000	4150.00000
.80000	697.82000	2578.90000	1805.23000	1289.45000
3248.82000	78.20000	54.74000	39.10000	159.16000
202.30000	144.50000	588.20000	101.15000	411.74000
294.10000	23012.89000	21.16000	289.00000	141.61000
72.25000	1197.16000	62460.95800	930.58000	2705.72000
1894.00400	6999.58000	27.72000	24.84969	52.56969

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

45

149.20000	1.00000	17.00000	23.30000	49.50000
34.90000	19.40000	23.00000	4420.00000	4570.00000
.80000	149.20000	2536.40000	3476.36000	7385.40000
5207.08000	17.00000	23.30000	49.50000	34.90000
396.10000	841.50000	593.30000	1153.35000	813.17000
1727.55000	22260.64000	1.00000	289.00000	542.89000
2450.25000	1218.01000	121324.96400	396.10000	593.30000
813.17000	13823.89000	23.28000	27.60186	50.88186

46

8.50000	1.00000	17.00000	23.50000	49.50000
35.50000	5.80000	6.20000	2810.00000	2930.00000
.90000	8.50000	144.50000	199.75000	420.75000
301.75000	17.00000	23.50000	49.50000	35.50000
399.50000	841.50000	603.50000	1163.25000	834.25000
1757.25000	72.25000	1.00000	289.00000	552.25000
2450.25000	1260.25000	7091.12500	399.50000	603.50000
834.25000	14182.25000	6.96000	18.00084	24.96084

47

7.60000	1.00000	17.00000	12.10000	49.50000
35.20000	14.20000	16.50000	3850.00000	3870.00000
.90000	7.60000	129.20000	91.96000	376.20000
267.52000	17.00000	12.10000	49.50000	35.20000
205.70000	841.50000	598.40000	598.95000	425.92000
1742.40000	57.76000	1.00000	289.00000	146.41000
2450.25000	1239.04000	3236.99200	205.70000	598.40000
425.92000	7240.64000	17.04000	23.57493	40.61493

48

159.10000	1.00000	17.00000	11.80000	49.50000
35.00000	23.30000	27.00000	5280.00000	4810.00000
.70000	159.10000	2704.70000	1877.38000	7875.45000
5568.50000	17.00000	11.80000	49.50000	35.00000
200.60000	841.50000	595.00000	584.10000	413.00000
1732.50000	25312.81000	1.00000	289.00000	139.24000
2450.25000	1225.00000	65708.30000	200.60000	595.00000
413.00000	7021.00000	27.96000	29.13465	57.09465

49

150.00000	8.30000	17.00000	24.40000	49.50000
34.70000	3.50000	5.80000	1830.00000	1120.00000
1.00000	1245.00000	2550.00000	3660.00000	7425.00000
5205.00000	141.10000	202.52000	410.85000	288.01000
414.80000	841.50000	589.90000	1207.80000	846.68000
1717.65000	22500.00000	68.89000	289.00000	595.36000
2450.25000	1204.09000	127002.00000	3442.84000	4896.17000
7027.44400	14393.56000	4.20000	6.72580	10.92580

50

80.90000	4.60000	25.00000	24.50000	49.50000
60.50000	2.60000	2.70000	367.00000	375.00000
.50000	372.14000	2022.50000	1982.05000	4004.55000
4894.45000	115.00000	112.70000	227.70000	278.30000
612.50000	1237.50000	1512.50000	1212.75000	1482.25000
2994.75000	6544.81000	21.16000	625.00000	600.25000
2450.25000	3660.25000	119914.02500	2817.50000	6957.50000
6818.35000	37056.25000	3.12000	5.77397	8.89397

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

51

82.50000	4.70000	9.00000	12.20000	49.50000
10.80000	45.80000	51.90000	19800.00000	15600.00000
.30000	387.75000	742.50000	1006.50000	4083.75000
891.00000	42.30000	57.34000	232.65000	50.76000
109.80000	445.50000	97.20000	603.90000	131.76000
534.60000	6806.25000	22.09000	81.00000	148.84000
2450.25000	116.64000	10870.20000	516.06000	456.84000
619.27200	1185.84000	54.96000	15.43614	70.39614

52

77.60000	4.50000	17.00000	18.80000	49.50000
35.20000	11.00000	11.30000	2770.00000	2210.00000
1.10000	349.20000	1319.20000	1458.88000	3841.20000
2731.52000	76.50000	84.60000	222.75000	158.40000
319.60000	841.50000	598.40000	930.60000	661.76000
1742.40000	6021.76000	20.25000	289.00000	353.44000
2450.25000	1239.04000	51352.57600	1438.20000	2692.80000
2977.92000	11249.92000	13.20000	13.46268	26.66268

53

80.10000	4.70000	17.00000	18.20000	49.50000
35.00000	7.40000	7.40000	2070.00000	1530.00000
1.10000	376.47000	1361.70000	1457.82000	3964.95000
2803.50000	79.90000	85.54000	232.65000	164.50000
309.40000	841.50000	595.00000	900.90000	637.00000
1732.50000	6416.01000	22.09000	289.00000	331.24000
2450.25000	1225.00000	51023.70000	1454.18003	2796.50000
2993.90000	10829.00000	8.88000	9.26736	18.14736

54

2.70000	5.10000	25.00000	18.60000	49.50000
10.10000	30.20000	34.40000	11700.00000	8260.00000
.40000	13.77000	67.50000	50.22000	133.65000
27.27000	127.50000	94.86000	252.45000	51.51000
465.00000	1237.50000	252.50000	920.70000	187.86000
499.95000	7.29000	26.01000	625.00000	345.96000
2450.25000	102.01000	507.22200	2371.50000	1287.75000
958.08600	4696.50000	36.24000	21.23192	57.47192

55

10.10000	5.50000	10.00000	19.10000	49.50000
10.00000	40.00000	43.60000	18300.00000	15800.00000
.30000	55.55000	101.00000	192.91000	499.95000
101.00000	55.00000	105.05000	272.25000	55.00000
191.00000	495.00000	100.00000	945.45000	191.00000
495.00000	102.01000	30.25000	100.00000	364.81000
2450.25000	100.00000	1929.10000	1050.50000	550.00000
1050.50000	1910.00000	48.00000	16.08440	64.08440

56

79.20000	4.30000	23.20000	14.50000	49.50000
10.00000	33.60000	42.40000	10200.00000	7350.00000
.30000	340.56000	1837.44000	1148.40000	3920.40000
792.00000	99.76000	62.35000	212.85000	43.00000
336.40000	1148.40000	232.00000	717.75000	145.00000
495.00000	6272.64000	18.49000	538.24000	210.25000
2450.25000	100.00000	11484.00000	1446.52000	997.60000
623.50000	3364.00000	40.32000	17.35894	57.67894

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

57

157.40000	4.30000	23.20000	18.80000	49.50000
60.00000	1.50000	2.20000	812.00000	846.00000
.90000	676.82000	3651.68000	2959.12000	7791.30000
9444.00000	99.76000	80.84000	212.85000	258.00000
436.16000	1148.40000	1392.00000	930.60000	1128.00000
2970.00000	24774.76000	18.49000	538.24000	353.44000
2450.25000	3600.00000	177547.20000	1875.48800	5985.60000
4850.40000	26169.50000	1.80000	11.98829	13.78829

58

81.70000	5.50000	10.00000	24.50000	49.50000
60.00000	1.40000	1.60000	1100.00000	1030.00000
.90000	449.35000	817.00000	2001.65000	4044.15000
4902.00000	55.00000	134.75000	272.25000	330.00000
245.00000	495.00000	600.00000	1212.75000	1470.00000
2970.00000	6674.89000	30.25000	100.00000	600.25000
2450.25000	3600.00000	120099.00000	1347.50000	3300.00000
8085.00000	14700.00000	1.68000	6.29124	7.97124

59

155.80000	4.30000	23.20000	18.90000	49.50000
10.00000	32.10000	43.80000	9840.00000	10600.00000
.40000	669.94000	3614.56000	2944.62000	7712.10000
1558.00000	99.76000	81.27000	212.85000	43.00000
438.48000	1148.40000	232.00000	935.55000	189.00000
495.00000	24273.64000	18.49000	538.24000	357.21000
2450.25000	100.00000	29446.20000	1885.46400	997.60000
812.70000	4384.80000	38.52000	25.03466	63.55466

60

75.10000	7.60000	23.20000	18.50000	97.50000
34.70000	1.00000	1.60000	301.00000	353.00000
.80000	570.76000	1742.32000	1389.35000	7322.25000
2605.97000	176.32000	140.60000	741.00000	263.72000
429.20000	2262.00000	805.04000	1803.75000	641.95000
3383.25000	5640.01000	57.76000	538.24000	342.25000
9506.25000	1204.09000	48210.44500	3261.92000	6118.30400
4878.82000	14893.24000	1.20000	2.89294	4.09294

61

79.20000	8.10000	25.00000	18.20000	97.50000
34.60000	5.00000	7.00000	1670.00000	1260.00000
.90000	641.52000	1980.00000	1441.44000	7722.00000
2740.32000	202.50000	147.42000	789.75000	280.26000
455.00000	2437.50000	865.00000	1774.50000	629.72000
3373.50000	6272.64000	65.61000	625.00000	331.24000
9506.25000	1197.16000	49873.82400	3685.50000	7006.50000
5100.73200	15743.00000	6.00000	11.09518	17.09518

62

75.10000	10.00000	10.00000	18.20000	97.50000
35.00000	3.80000	3.30000	2170.00000	1700.00000
.90000	751.00000	751.00000	1366.82000	7322.25000
2628.50000	100.00000	182.00000	975.00000	350.00000
182.00000	975.00000	350.00000	1774.50000	637.00000
3412.50000	5640.01000	100.00000	100.00000	331.24000
9506.25000	1225.00000	47838.70000	1820.00000	3500.00000
6370.00000	6370.00000	4.56000	6.05710	10.61710

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

63

77.60000	8.50000	9.00000	18.50000	97.50000
35.10000	13.60000	16.00000	6690.00000	4320.00000
.90000	659.60000	698.40000	1435.60000	7566.00000
2723.76000	76.50000	157.25000	828.75000	298.35000
166.50000	877.50000	315.90000	1803.75000	649.35000
3422.25000	6021.76000	72.25000	81.00000	342.25000
9506.25000	1232.01000	50389.56000	1415.25000	2685.15000
5519.47500	5844.15000	16.32000	13.89252	30.21252

64

77.60000	10.00000	10.00000	18.80000	8.50000
35.00000	1.20000	1.80000	930.00000	847.00000
.80000	776.00000	776.00000	1458.88000	659.60000
2716.00000	100.00000	188.00000	85.00000	350.00000
188.00000	85.00000	350.00000	159.80000	658.00000
297.50000	6021.76000	100.00000	100.00000	353.44000
72.25000	1225.00000	51060.80000	1880.00000	3500.00000
6580.00000	6580.00000	1.44000	3.01786	4.45786

65

75.90000	1.00000	10.00000	18.50000	8.50000
34.80000	11.20000	11.80000	4050.00000	3810.00000
.90000	75.90000	759.00000	1404.15000	645.15000
2641.32000	10.00000	18.50000	8.50000	34.80000
185.00000	85.00000	348.00000	157.25000	643.80000
295.80000	5760.81000	1.00000	100.00000	342.25000
72.25000	1211.04000	48864.42000	185.00000	348.00000
643.80000	6438.00000	13.44000	13.49746	26.93746

66

72.70000	5.50000	10.00000	24.10000	49.50000
10.00000	38.40000	45.40000	20100.00000	16100.00000
.20000	399.85000	727.00000	1752.07000	3598.65000
727.00000	55.00000	132.55000	272.25000	55.00000
241.00000	495.00000	100.00000	1192.95000	241.00000
495.00000	5285.29000	30.25000	100.00000	580.81000
2450.25000	100.00000	17520.70000	1325.50000	550.00000
1325.50000	2410.00000	46.08000	16.38980	62.46980

67

6.80000	4.20000	23.20000	18.40000	49.50000
59.50000	1.40000	2.60000	714.00000	690.00000
.90000	28.56000	157.76000	125.12000	336.60000
404.60000	97.44000	77.28000	207.90000	249.90000
426.88000	1148.40000	1380.40000	910.80000	1094.80000
2945.25000	46.24000	17.64000	538.24000	338.56000
2450.25000	3540.25000	7444.64000	1792.89600	5797.68000
4598.16000	25399.36000	1.68000	9.69621	11.37621

68

74.30000	4.20000	23.20000	12.70000	49.50000
60.00000	3.00000	3.30000	714.00000	638.00000
.80000	312.06000	1723.76000	943.61000	3677.85000
4458.00000	97.44000	52.34000	207.90000	252.00000
294.64000	1148.40000	1392.00000	628.65000	762.00000
2970.00000	5520.49000	17.64000	538.24000	161.29000
2450.25000	3600.00000	56616.60000	1237.48800	5846.40000
3200.40000	17678.40000	3.60000	9.04082	12.64082

BEST COPY AVAILABLE

Table A-2. — Phase II transformed variable listing and data matrix. — Continued

69

69.40000	4.20000	23.20000	23.40000	49.50000
10.00000	26.20000	35.20000	11400.00000	8280.00000
.50000	291.48000	1610.08000	1623.96000	3435.30000
694.00000	97.44000	98.28000	207.90000	42.00000
542.88000	1148.40000	232.00000	1158.30000	234.00000
495.00000	4816.36000	17.64000	538.24000	547.56000
2450.25000	100.00000	16239.60000	2280.09600	974.40000
982.80000	5428.80000	31.44000	19.55537	50.99537

70

80.90000	.90000	9.00000	18.40000	97.50000
34.70000	19.00000	20.20000	6850.00000	6850.00000
.80000	72.81000	728.10000	1488.56000	7887.75000
2807.23000	8.10000	16.56000	87.75000	31.23000
165.60000	877.50000	312.30000	1794.00000	638.48000
3383.25000	6544.81000	.81000	81.00000	338.56000
9506.25000	1204.09000	51653.03200	149.04000	281.07000
574.63200	5746.32000	22.80000	21.77762	44.57762

71

82.50000	.90000	25.00000	17.90000	97.50000
34.60000	4.00000	3.80000	1720.00000	1210.00000
.80000	74.25000	2062.50000	1476.75000	8043.75000
2854.50000	22.50000	16.11000	87.75000	31.14000
447.50000	2437.50000	865.00000	1745.25000	619.34000
3373.50000	6806.25000	.81000	625.00000	320.41000
9506.25000	1197.16000	51095.55000	402.75000	778.50000
557.40600	15483.50000	4.80000	10.65490	15.45490

72

82.50000	4.10000	17.00000	18.20000	49.50000
34.90000	8.80000	9.80000	2320.00000	2210.00000
.90000	338.25000	1402.50000	1501.50000	4083.75000
2879.25000	69.70000	74.62000	202.95000	143.09000
309.40000	841.50000	593.30000	900.90000	635.18000
1727.55000	6806.25000	16.81000	289.00000	331.24000
2450.25000	1218.01000	52402.35000	1268.54000	2432.53000
2604.23800	10798.06000	10.56000	13.34794	23.90794

73

76.80000	4.60000	17.00000	17.90000	49.50000
35.10000	7.90000	9.30000	2520.00000	1890.00000
1.20000	353.28000	1305.60000	1374.72000	3801.60000
2695.68000	78.20000	82.34000	227.70000	161.46000
304.30000	841.50000	596.70000	886.05000	628.29000
1737.45000	5898.24000	21.16000	289.00000	320.41000
2450.25000	1232.01000	48252.67200	1399.78000	2744.82000
2890.13400	10680.93000	9.48000	11.48063	20.96063

74

76.80000	4.50000	17.00000	18.10000	49.50000
35.10000	15.50000	17.40000	4250.00000	2820.00000
.90000	345.60000	1305.60000	1390.08000	3801.60000
2695.68000	76.50000	81.45000	222.75000	157.95000
307.70000	841.50000	596.70000	895.95000	635.31000
1737.45000	5898.24000	20.25000	289.00000	327.61000
2450.25000	1232.01000	48791.80800	1384.65000	2685.15000
2858.89500	10800.27000	18.60000	17.12982	35.72982

BEST COPY AVAILABLE

Table A-3. — Phase II effluent brine regression results.

```
**********************************************************************************
STEP NUMBER 17
VARIABLE'X5^2' ADDED
R-SQUARED =  .85290043964

                                    AOV

SOURCE              DF      SUM OF SQUARES         MEAN SQUARE         F-VALUE
TOTAL               73        19096.22938
REGRESSION           9        16287.18244          1809.68694           41.23
RESIDUAL            64         2809.04695            43.89136

STANDARD ERROR =  6.62505536168

                 F TO   PART                F TO        REGRESSION COEFFICIENTS          STD
#--VARIABLE     ENTER   CORR     TOL     DELETE  STD.FORMAT              E-FORMAT       ERROR
 1.COL'M PRES     .01   .013   .183
 2.CATL CONC      .08   .035   .049
 3.RESID TIME     .04   .025   .224
 4.COL'M TEMP     .55   .093   .617
 5.PORE SIZE                           14.20       .47667  .476667216070E+00      .1265
 6.AIR MASSFL                          45.86     -1.51670 -.151670280321E+01      .2240
12.X1*X2          .13   .046   .210
13.X1*X3          .02   .019   .225
14.X1*X4         1.43   .149   .258
15.X1*X5                               4.51       .00066  .664160509526E-03      .0003
16.X1*X6          .00   .005   .204
17.X2*X3          .04   .025   .099
18.X2*X4          .55   .093   .161
19.X2*X5          .02   .016   .200
20.X2*X6         1.36   .145   .063
21.X3*X4                              35.70      -.04875 -.487530962158E-01      .0082
22.X3*X5          .58   .095   .124
23.X3*X6          .65   .101   .102
24.X4*X5          .23   .060   .089
25.X4*X6          .55   .093   .126
26.X5*X6                              13.21      -.00767 -.766750031096E-02      .0021
27.X1^2           .28   .067   .290
28.X2^2                               18.64      -.20355 -.203547251878E+00      .0472
29.X3^2           .31   .070   .236
30.X4^2           .33   .072   .632
31.X5^2                                4.74      -.00191 -.190681509825E-02      .0009
32.X6^2                               30.57       .01478  .147806660544E-01      .0027
33.X1*X4*X6       .79   .111   .262
34.X2*X3*X4       .01   .013   .095
35.X2*X3*X6                            5.73       .00167  .167314227455E-02      .0007
36.X2*X4*X6      1.46   .150   .166
37.X3*X4*X6       .57   .094   .083

Constant =  56.549349928
```


BEST COPY AVAILABLE

Table A-3. — Phase II effluent brine regression results. — Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	56.88000	46.49290	10.38710	1.56785	
2	2.40000	.96650	1.43350	.21637	
3	42.24000	41.08345	1.15655	.17457	
4	17.28000	14.91680	2.36320	.35671	
5	4.56000	10.96802	-6.40802	-.96724	
6	2.16000	5.20517	-3.04517	-.45964	
7	1.20000	6.76921	-5.56921	-.84063	
8	5.88000	14.11429	-8.23429	-1.24290	
9	4.08000	14.41485	-10.33485	-1.55996	
10	41.64000	38.16073	3.47927	.52517	
11	6.72000	13.48214	-6.76214	-1.02069	
12	.72000	3.75407	-3.03407	-.45797	
13	6.48000	6.06647	.41353	.06242	
14	1.44000	13.78599	-12.34599	-1.86353	
15	9.96000	9.11936	.84064	.12689	
16	.72000	-7.81021	8.53021	1.28757	
17	2.88000	5.50460	-2.62460	-.39616	
18	1.20000	4.27642	-3.07642	-.46436	
19	18.36000	15.99153	2.36847	.35750	
20	6.96000	5.22776	1.73224	.26147	
21	1.20000	3.69176	-2.49176	-.37611	
22	2.40000	19.43425	-17.03425	-2.57119	**
23	48.96000	48.74550	.21450	.03238	
24	47.88000	45.17549	2.70451	.40822	
25	3.48000	.79010	2.68990	.40602	
26	3.84000	9.62909	-5.78909	-.87382	
27	39.00000	28.96897	10.03103	1.51411	
28	8.52000	11.74259	-3.22259	-.48643	
29	23.76000	15.25691	8.50309	1.28347	
30	15.84000	14.64254	1.19746	.18075	
31	7.08000	11.24862	-4.16862	-.62922	
32	5.16000	7.26887	-2.10887	-.31832	
33	39.96000	39.80978	.15022	.02267	
34	27.00000	20.83351	6.16649	.93078	
35	19.92000	20.67425	-.75425	-.11385	
36	49.68000	54.21039	-4.53039	-.68383	
37	9.84000	-6.25702	16.09702	2.42972	**
38	4.92000	7.18919	-2.26919	-.34252	
39	14.64000	32.28311	-17.64311	-2.66309	**
40	5.52000	1.52938	3.99062	.60235	
41	3.48000	3.29907	.18093	.02731	
42	25.92000	13.53502	12.38498	1.86942	
43	8.64000	-.69117	9.33117	1.40847	
44	27.72000	14.63879	13.08121	1.97451	
45	23.28000	13.67940	9.60060	1.44913	
46	6.96000	8.39165	-1.43165	-.21610	
47	17.04000	18.05726	-1.01726	-.15355	
48	27.96000	23.45264	4.50736	.68035	
49	4.20000	6.34801	-2.14801	-.32423	
50	3.12000	-5.01741	8.13741	1.22828	
51	54.96000	50.34396	4.61604	.69676	
52	13.20000	14.39154	-1.19154	-.17985	
53	8.88000	14.94172	-6.06172	-.91497	
54	36.24000	32.10681	4.13319	.62387	
55	48.00000	43.77096	4.22904	.63834	
56	40.32000	42.09660	-1.77660	-.26816	
57	1.80000	5.06965	-3.26965	-.49353	
58	1.68000	5.01348	-3.33348	-.50316	
59	38.52000	39.63818	-1.11818	-.16878	

BEST COPY AVAILABLE

Table A-3. — Phase II effluent brine regression results. — Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
60	1.20000	6.54256	-5.34256	-.80642	
61	6.00000	5.56246	.43754	.06604	
62	4.56000	5.24547	-.68547	-.10347	
63	16.32000	10.32530	5.99470	.90485	
64	1.44000	-.02234	1.46234	.22073	
65	13.44000	15.10179	-1.66179	-.25083	
66	46.08000	43.39134	2.68866	.40583	
67	1.68000	.49454	1.18546	.17894	
68	3.60000	9.17731	-5.57731	-.84185	
69	31.44000	31.84208	-.40208	-.06069	
70	22.80000	21.59495	1.20505	.18189	
71	4.80000	8.91133	-4.11133	-.62057	
72	10.56000	15.57268	-5.01268	-.75662	
73	9.48000	15.09868	-5.61868	-.84810	
74	18.60000	15.01832	3.58168	.54063	

BEST COPY AVAILABLE

Table A-4. — Phase II effluent gas regression results.

```
**********************************************************************************
STEP NUMBER 11
VARIABLE 'X5^2' ADDED
R-SQUARED =  .59386857387

                                      AOV

SOURCE              DF      SUM OF SQUARES         MEAN SQUARE         F-VALUE
TOTAL               73          4343.79844
REGRESSION           9          2579.64539           286.62727           10.40
RESIDUAL            64          1764.15306            27.56489

STANDARD ERROR =  5.2502277566

                  F TO   PART          F TO        REGRESSION COEFFICIENTS        STD
#--VARIABLE     ENTER   CORR    TOL DELETE  STD.FORMAT             E-FORMAT      ERROR
 1.COL'M PRES     .72   .106   .107
 2.CATL CONC      .07   .033   .156
 3.RESID TIME                    4.09        .45661  .456605046870E+00      .2259
 4.COL'M TEMP                    8.06       -.50506 -.505056982273E+00      .1779
 5.PORE SIZE                    14.12        .35483  .354826356667E+00      .0944
 6.AIR MASSFL                   10.45        .45351  .453511921034E+00      .1403
12.X1*X2          .01   .012   .220
13.X1*X3          .03   .022   .117
14.X1*X4         2.66   .201   .140
15.X1*X5          .10   .040   .164
16.X1*X6          .51   .089   .160
17.X2*X3          .78   .110   .185
18.X2*X4          .01   .009   .114
19.X2*X5          .29   .068   .243
20.X2*X6          .39   .078   .028
21.X3*X4          .04   .024   .023
22.X3*X5         2.29   .187   .067
23.X3*X6                        5.86       -.01380 -.138002821323E-01      .0057
24.X4*X5          .29   .068   .024
25.X4*X6          .09   .037   .031
26.X5*X6                        7.51       -.00458 -.458112501318E-02      .0017
27.X1^2                         5.64        .00020  .195062429273E-03      .0001
28.X2^2          .29   .068   .195
29.X3^2         1.07   .129   .023
30.X4^2          .77   .110   .015
31.X5^2                         5.73       -.00153 -.152962146521E-02      .0006
32.X6^2          .10   .039   .058
33.X1*X4*X6     1.77   .165   .181
34.X2*X3*X4      .56   .094   .159
35.X2*X3*X6     1.49   .152   .066
36.X2*X4*X6                    24.96       -.00174 -.173847145753E-02      .0003
37.X3*X4*X6      .01   .011   .033

Constant =  6.62973972411
```


BEST COPY AVAILABLE

Table A-4. — Phase II effluent gas regression results. — Continued

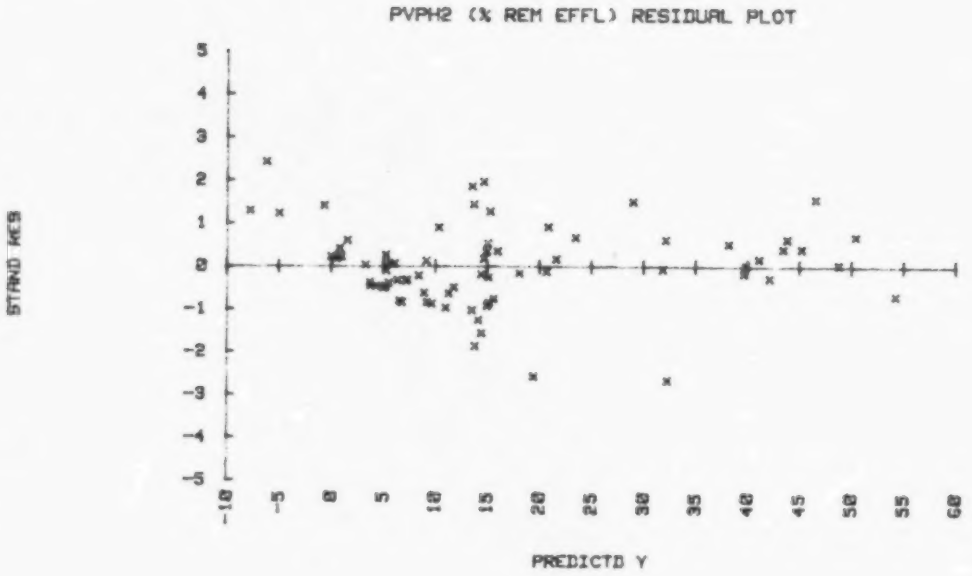
OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	17.40780	14.91554	2.49226	.47470	
2	3.55552	3.15903	.39649	.07552	
3	22.44486	23.87685	-1.43198	-.27275	
4	24.83411	14.77113	10.06298	1.91668	
5	7.87423	15.50414	-7.62991	-1.45325	
6	7.03466	11.36510	-4.33044	-.82481	
7	6.69541	7.91435	-1.21894	-.23217	
8	10.66050	14.00340	-3.34291	-.63672	
9	4.83962	14.28501	-9.44539	-1.79904	
10	29.90884	24.56415	5.34469	1.01799	
11	12.17477	16.42938	-4.25461	-.81037	
12	4.77299	7.09563	-2.32263	-.44239	
13	11.75790	9.84701	1.91089	.36396	
14	3.94923	11.90029	-7.95106	-1.51442	
15	9.68423	8.44832	1.23592	.23540	
16	4.21150	-2.48482	6.69632	1.27543	
17	3.63475	6.32208	-2.68733	-.51185	
18	2.32593	9.15189	-6.82596	-1.30013	
19	13.36571	14.62371	-1.25800	-.23961	
20	19.52117	18.13902	1.38215	.26326	
21	5.02566	3.81993	1.20573	.22965	
22	1.14047	8.74247	-7.60200	-1.44794	
23	11.70700	19.19391	-7.48691	-1.42602	
24	16.12146	12.43919	3.68226	.70135	
25	7.57911	6.07692	1.50219	.28612	
26	9.54543	14.04088	-4.49545	-.85624	
27	20.95044	17.78188	3.16856	.60351	*
28	13.49059	19.64215	-6.15156	-1.17168	
29	30.32011	19.53199	10.78813	2.05479	**
30	21.92670	14.51939	7.40731	1.41086	
31	10.82838	16.28105	-5.45266	-1.03856	
32	11.34311	12.65390	-1.31079	-.24966	
33	23.84767	21.18189	2.66577	.50774	
34	26.41276	19.82822	6.58454	1.25414	
35	14.85728	17.26588	-2.40860	-.45876	
36	24.40146	24.15525	.24621	.04689	
37	19.20966	11.27119	7.93847	1.51202	
38	11.40949	17.04880	-5.63931	-1.07411	
39	6.86581	10.98202	-4.11621	-.78401	
40	10.96132	14.34096	-3.37965	-.64371	
41	4.33083	4.39111	-.06028	-.01148	
42	27.57780	14.20822	13.36958	2.54648	**
43	11.76884	6.04287	5.72597	1.09061	
44	24.84969	18.71051	6.13917	1.16932	
45	27.60186	19.09443	8.50743	1.62039	
46	18.00084	14.62393	3.37691	.64319	
47	23.57493	21.09098	2.48394	.47311	
48	29.13465	26.19284	2.94181	.56032	
49	6.72580	7.78379	-1.05798	-.20151	
50	5.77397	1.75528	4.01869	.76543	
51	15.43614	19.75197	-4.31583	-.82203	
52	13.46268	14.43387	-.97119	-.18498	
53	9.26736	14.78760	-5.52024	-1.05143	
54	21.23192	19.60814	1.62378	.30928	
55	16.08440	14.44622	1.63818	.31202	
56	17.35894	22.92102	-5.56208	-1.05940	
57	11.98829	12.33898	-.35069	-.06679	
58	6.29124	5.20893	1.08231	.20615	
59	25.03466	23.88117	1.15349	.21970	

BEST COPY AVAILABLE

Table A-4. — Phase II effluent gas regression results. — Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
60	2.89294	9.68049	-6.78754	-1.29281	
61	11.09518	9.56336	1.53182	.29176	
62	6.05710	7.49418	-1.43708	-.27372	
63	13.89252	8.91041	4.98211	.94893	
64	3.01786	4.02164	-1.00378	-.19119	
65	13.49746	14.38685	-.88940	-.16940	
66	16.38980	12.45392	3.93588	.74966	
67	9.69621	8.20262	1.49359	.28448	
68	9.04082	14.53252	-5.49170	-1.04599	
69	19.55537	17.51731	2.03806	.38819	
70	21.77762	17.70635	4.07127	.77545	
71	10.65490	17.71740	-7.06251	-1.34518	
72	13.34794	15.54192	-2.19398	-.41788	
73	11.48063	15.01773	-3.53710	-.67370	
74	17.12982	14.97103	2.15880	.41118	

BEST COPY AVAILABLE



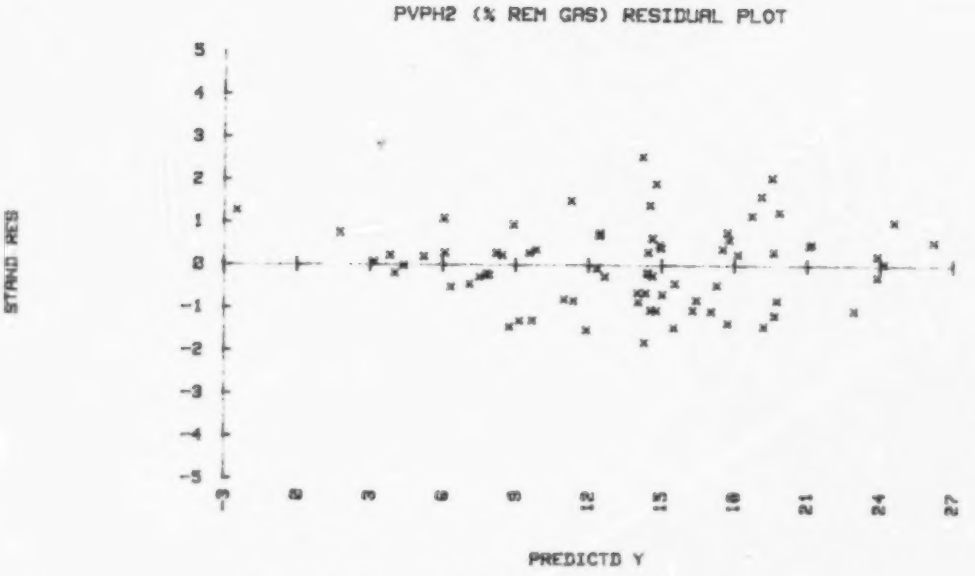


Figure A-1. – Phase II standardized residual plots.

BEST COPY AVAILABLE

BLANK PAGE

APPENDIX B

Phase IIa Test Data

BEST COPY AVAILABLE

BLANK PAGE

Table B-1. — Phase IIa test data.

Run No.	X_1 Catalyst conc. (mg/L of Ni^{+2})	X_2 Residence time (min)	X_3 First stage temp. (°C)	X_4 Air mass-flow rate (sL/min)	Influent ΣS^{-2} conc. (mg/L)	$Y_1(X_5)$ Filtered interstage ΣS^{-2} conc. (mg/L)	$Y_2(X_6)$ Effluent ΣS^{-2} conc. (mg/L)	$Y_3(X_7)$ Filtered effluent ΣS^{-2} conc. (mg/L)	$Y_4(X_8)$ Interstage H_2S conc. (mg/m^3)*	$Y_5(X_9/X_{10})$ Effluent H_2S conc. (mg/m^3)**	pH influent/ effluent
1	5.0	15	14.8	35.0	80.8	11.2	6.0	3.6	4 030	840/ 810	6.7/7.5
2	4.9	27.5	19.9	35.1	76.8	3.6	2.4	2.4	1 260	168/ 90	6.8/7.7
3	5.1	40	24.4	35.3	70.4	0.8	0.4	1.6	420	70/ 40	6.9/7.8
4	0.9	27.5	15.5	35.6	76.0	4.8	1.6	2.8	3 370	868/ 470	7.0/7.8
5	0.9	27.5	19.8	60.0	72.8	5.6	1.6	0.8	1 820	378/ 300	7.2/8.1
6	0.9	27.5	19.8	10.1	76.8	22.8	3.2	2.4	6 720	1930/ 940	7.4/7.8
7	4.6	40	17.3	35.1	73.1	2.6	3.9	2.5	994	126/ 40	7.4/7.9
8	4.7	15	19.8	10.1	79.5	34.2	18.3	20.5	13 700	6720/4640	7.3/7.0
9	5.0	27.5	19.9	35.4	77.0	2.7	3.4	2.6	1 410	70/ 130	7.4/7.8
10	9.1	15	21.0	35.2	77.6	1.2	4.4	2.0	2 050	203/ 130	7.4/7.9
11	9.3	40	20.1	35.1	77.1	2.6	1.1	2.1	399	21/ 85	7.5/8.2
12	9.1	27.5	24.2	35.2	78.6	2.6	5.1	3.3	560	21/ 0	7.5/8.2
13	5.1	27.5	16.8	10.1	80.3	34.2	5.1	5.3	9 800	2060/1280	7.4/8.0
14	4.9	27.5	20.4	35.1	77.1	5.0	5.5	4.5	1 630	70/ 85	7.6/8.0
15	4.9	27.5	24.2	60.3	76.2	2.6	2.7	0.9	588	21/ 43	7.6/8.1
16	1.0	15	20.2	35.1	78.6	21.9	4.2	5.8	5 210	1880/1410	7.5/7.5
17	1.0	40	20.5	35.1	80.3	10.2	5.1	4.9	1 880	168/ 130	7.5/7.7
18	0.9	27.5	24.2	35.2	73.8	11.9	4.2	4.2	2 460	336/ 260	7.6/7.9
19	4.6	40	20.7	60.1	81.0	4.7	4.6	4.2	410	21/ 130	7.4/7.4
20	4.5	27.5	24.3	10.2	76.2	20.8	4.6	3.0	6 840	350/ 260	7.5/7.3
21	5.1	15	20.5	60.2	80.0	8.0	4.0	3.6	1 740	175/ 260	7.5/7.5
22	8.7	27.5	17.2	35.1	77.0	3.1	3.0	1.8	1 090	42/ 170	7.3/7.4
23	9.0	27.5	20.6	10.1	80.2	37.1	6.6	6.1	11 000	1470/1280	7.5/7.4
24	8.9	27.5	20.5	60.1	81.1	1.8	4.7	2.5	560	21/ 0	7.5/7.6
25	5.3	40	20.7	10.1	75.5	38.2	3.5	2.5	8 740	588/ 210	7.5/7.7
26	5.0	15	24.4	35.2	79.5	3.8	3.5	2.9	2 030	140/ 170	7.5/7.8
27	4.8	27.5	16.2	59.9	81.6	4.8	2.4	2.0	1 050	91/ 130	7.3/7.5
1a	5.0	15	16.0	35.2	81.6	23.6	3.2	3.6	5 780	1500/1190	7.4/7.4
2a	4.8	27.5	20.6	35.0	76.8	4.8	2.0	2.4	1 010	56/ 40	7.4/7.5
3a	5.3	40	24.3	35.3	80.2	3.1	3.8	3.0	371	21/ 40	7.5/7.8

* Gastec detector tubes.
** Gastec detector tubes/titrimetric (iodine) method.

BEST COPY AVAILABLE

Table 6-2. — Phase IIa (effluent) transformed variable listing and data matrix.

```
+-+-+-
```

Table B-2. — Phase IIa (effluent) transformed variable listing and data matrix. — Continued

3

5.10000	40.00000	24.40000	35.30000	.80000
.40000	1.60000	420.00000	70.00000	40.00000
204.00000	124.44000	180.03000	976.00000	1412.00000
861.32000	26.01000	1600.00000	595.36000	1246.09000
4977.60000	7201.20000	4392.73200	34452.80000	1040.40000
634.64400	918.15300	8160.00000	39040.00000	56480.00000
3036.33600	23814.40000	21016.20800	6355.05900	49843.60000
30404.59600	43986.97700	2.05440	.60322	2.65762

4

.90000	27.50000	15.50000	35.60000	4.80000
1.60000	2.80000	3370.00000	868.00000	470.00000
24.75000	13.95000	32.04000	426.25000	979.00000
551.80000	.81000	756.25000	240.25000	1267.36000
383.62500	881.10000	496.62000	15174.50000	22.27500
12.55500	28.83600	680.62500	11721.87500	26922.50000
216.22500	6606.87500	8552.90000	1140.62400	34852.40000
19644.08000	45118.01600	3.59520	5.18616	8.78136

5

.90000	27.50000	19.80000	60.00000	5.60000
1.60000	.80000	1820.00000	378.00000	300.00000
24.75000	17.82000	54.00000	544.50000	1650.00000
1188.00000	.81000	756.25000	392.04000	3600.00000
490.05000	1485.00000	1069.20000	32670.00000	22.27500
16.03800	48.60000	680.62500	14973.75000	45375.00000
352.83600	10781.10000	23522.40000	3240.00000	99000.00000
71280.00000	216000.00000	1.02720	3.80644	4.83364

6

.90000	27.50000	19.80000	10.10000	22.80000
3.20000	2.40000	6720.00000	1930.00000	940.00000
24.75000	17.82000	9.09000	544.50000	277.75000
199.98000	.81000	756.25000	392.04000	102.01000
490.05000	249.97500	179.98200	5499.45000	22.27500
16.03800	8.18100	680.62500	14973.75000	7638.12500
352.83600	10781.10000	3959.60400	91.80900	2805.27500
2019.79800	1030.30100	3.08160	3.27156	6.35316

7

4.60000	40.00000	17.30000	35.10000	2.60000
3.90000	2.50000	994.00000	126.00000	40.00000
184.00000	79.58000	161.46000	692.00000	1404.00000
607.23000	21.16000	1600.00000	299.29000	1232.01000
3183.20000	6458.40000	2793.25800	24289.20000	846.40000
366.06800	742.71600	7360.00000	27680.00000	56160.00000
1376.73400	11971.60000	10505.07900	5667.24600	49280.40000
21313.77300	43243.55100	3.21000	1.07965	4.28965

8

4.70000	15.00000	19.80000	10.10000	34.20000
18.30000	20.50000	13700.00000	6720.00000	4640.00000
70.50000	93.06000	47.47000	297.00000	151.50000
199.98000	22.09000	225.00000	392.04000	102.01000
1395.90000	712.05000	939.90600	2999.70000	331.35000
437.38200	223.10900	1057.50000	4455.00000	2272.50000
1842.58800	5880.60000	3959.60400	479.44700	1530.15000
2019.79800	1030.30100	26.32200	6.21334	32.53534

BEST COPY AVAILABLE

Table B-2. — Phase IIa (effluent) transformed variable listing and data matrix. — Continued

```
 9
        5.00000        27.50000        19.90000        35.40000         2.70000
        3.40000         2.60000      1410.00000        70.00000       130.00000
      137.50000        99.50000       177.00000       547.25000       973.50000
      704.46000        25.00000       756.25000       396.01000      1253.16000
     2736.25000      4867.50000      3522.30000     19372.65000       687.50000
      497.50000       885.00000      3781.25000     15049.37500     26771.25000
     1980.05000     10890.27500     14018.75400      6265.80000     34461.90000
    24937.88400     44361.86400         3.33840         .41589         3.75429

10
        9.10000        15.00000        21.00000        35.20000         1.20000
        4.40000         2.00000      2050.00000       203.00000       130.00000
      136.50000       191.10000       320.32000       315.00000       528.00000
      739.20000        82.81000       225.00000       441.00000      1239.04000
     2866.50000      4804.80000      6726.72000     11088.00000      1242.15000
     1739.01000      2914.91200      2047.50000      4725.00000      7920.00000
     4013.10000      6615.00000     15523.20000     11275.26400     18585.60000
    26019.84000     43614.20800         2.56800         .65414         3.22214

11
        9.30000        40.00000        20.10000        35.10000         2.60000
        1.10000         2.10000       399.00000        21.00000        85.00000
      372.00000       186.93000       326.43000       804.00000      1404.00000
      705.51000        86.49000      1600.00000       404.01000      1232.01000
     7477.20000     13057.20000      6561.24300     28220.40000      3459.60000
     1738.44900      3035.79900     14880.00000     32160.00000     56160.00000
     3757.29300     16160.40000     14180.75100     11457.69300     49280.40000
    24763.40100     43243.55100         2.69640         .17994         2.87634

12
        9.10000        27.50000        24.20000        35.20000         2.60000
        5.10000         3.30000       560.00000        21.00000         0.00000
      250.25000       220.22000       320.32000       665.50000       968.00000
      851.84000        82.81000       756.25000       585.64000      1239.04000
     6056.05000      8808.80000      7751.74400     23425.60000      2277.27500
     2004.00200      2914.91200      6881.87500     18301.25000     26620.00000
     5329.32400     16105.10000     20614.52800     11275.26400     34073.60000
    29984.76800     43614.20800         4.23720         .12406         4.36126

13
        5.10000        27.50000        16.80000        10.10000        34.20000
        5.10000         5.30000      9800.00000      2060.00000      1280.00000
      140.25000        85.68000        51.51000       462.00000       277.75000
      169.68000        26.01000       756.25000       282.24000       102.01000
     2356.20000      1416.52500       865.36800      4666.20000       715.27500
      436.96800       262.70100      3856.87500     12705.00000      7638.12500
     1439.42400      7761.60000      2850.62400       520.25100      2805.27500
     1713.76800      1030.30100         6.80520         3.49192        10.29712

14
        4.90000        27.50000        20.40000        35.10000         5.00000
        5.50000         4.50000      1630.00000        70.00000        85.00000
      134.75000        99.96000       171.99000       561.00000       965.25000
      716.04000        24.01000       756.25000       416.16000      1232.01000
     2748.90000      4729.72500      3508.59600     19691.10000       660.27500
      489.80400       842.75100      3705.62500     15427.50000     26544.37500
     2039.18400     11444.40000     14607.21600      6036.84900     33880.27500
    25133.00400     43243.55100         5.77800         .41236         6.19036
```


BEST COPY AVAILABLE

Table B-2. — Phase IIa (effluent) transformed variable listing and data matrix. — Continued

15

4.90000	27.50000	24.20000	60.30000	2.60000
2.70000	.90000	588.00000	21.00000	43.00000
134.75000	118.58000	295.47000	665.50000	1658.25000
1459.26000	24.01000	756.25000	585.64000	3636.09000
3260.95000	8125.42500	7150.37400	40129.65000	660.27500
581.04200	1447.80300	3705.62500	18301.25000	45601.87500
2869.63600	16105.10000	35314.09200	17816.84100	99992.47500
87993.37800	219256.22700	1.15560	.21253	1.36813

16

1.00000	15.00000	20.20000	35.10000	21.90000
4.20000	5.80000	5210.00000	1880.00000	1410.00000
15.00000	20.20000	35.10000	303.00000	526.50000
709.02000	1.00000	225.00000	408.04000	1232.01000
303.00000	526.50000	709.02000	10635.30000	15.00000
20.20000	35.10000	225.00000	4545.00000	7897.50000
408.04000	6120.60000	14322.20400	1232.01000	18480.15000
24886.60200	43243.55100	7.44720	6.04087	13.48807

17

1.00000	40.00000	20.50000	35.10000	10.20000
5.10000	4.90000	1880.00000	168.00000	130.00000
40.00000	20.50000	35.10000	820.00000	1404.00000
719.55000	1.00000	1600.00000	420.25000	1232.01000
820.00000	1404.00000	719.55000	28782.00000	40.00000
20.50000	35.10000	1600.00000	32800.00000	56160.00000
420.25000	16810.00000	14750.77500	1232.01000	49280.40000
25256.20500	43243.55100	6.29160	1.43953	7.73113

18

.90000	27.50000	24.20000	35.20000	11.90000
4.20000	4.20000	2460.00000	336.00000	260.00000
24.75000	21.78000	31.68000	665.50000	968.00000
851.84000	.81000	756.25000	585.64000	1239.04000
598.95000	871.20000	766.65600	23425.60000	22.27500
19.60200	28.51200	680.62500	18301.25000	26620.00000
527.07600	16105.10000	20614.52800	1115.13600	34073.60000
29984.76800	43614.20800	5.39280	1.98499	7.37779

19

4.60000	40.00000	20.70000	60.10000	4.70000
4.60000	4.20000	410.00000	21.00000	130.00000
184.00000	95.22000	276.46000	828.00000	2404.00000
1244.07000	21.16000	1600.00000	428.49000	3612.01000
3808.80000	11058.40000	5722.72200	49762.80000	846.40000
438.01200	1271.71600	7360.00000	33120.00000	96160.00000
1971.05400	17139.60000	25752.24900	16615.24600	144480.40000
74768.60700	217081.80100	5.39280	.30810	5.70090

20

4.50000	27.50000	24.30000	10.20000	20.80000
4.60000	3.00000	6840.00000	350.00000	260.00000
123.75000	109.35000	45.90000	668.25000	280.50000
247.86000	20.25000	756.25000	590.49000	104.04000
3007.12500	1262.25000	1115.37000	6816.15000	556.87500
492.07500	206.55000	3403.12500	18376.87500	7713.75000
2657.20500	16238.47500	6022.99800	468.18000	2861.10000
2528.17200	1061.20800	3.85200	.59916	4.45116

BEST COPY AVAILABLE

Table B-2. — Phase IIa (effluent) transformed variable listing and data matrix. — Continued

```
21
      5.10000       15.00000       20.50000       60.20000        8.00000
      4.00000        3.60000     1740.00000      175.00000      260.00000
     76.50000      104.55000      307.02000      307.50000      903.00000
   1234.10000       26.01000      225.00000      420.25000     3624.04000
   1568.25000     4605.30000     6293.91000    18511.50000      390.15000
    533.20500     1565.80200     1147.50000     4612.50000    13545.00000
   2143.27500     6303.75000    25299.05000    18482.60400    54360.60000
  74292.82000   218167.20800        4.62240         .96443        5.58683

22
      8.70000       27.50000       17.20000       35.10000        3.10000
      3.00000        1.80000     1090.00000       42.00000      170.00000
    239.25000      149.64000      305.37000      473.00000      965.25000
    603.72000       75.69000      756.25000      295.84000     1232.01000
   4115.10000     8397.67500     5252.36400    16602.30000     2081.47500
   1301.86800     2656.71900     6579.37500    13007.50000    26544.37500
   2573.80800     8135.60000    10383.98400    10718.48700    33880.27500
  21190.57200    43243.55100        2.31120         .24742        2.55862

23
      9.00000       27.50000       20.60000       10.10000       37.10000
      6.60000        6.10000     11000.00000     1470.00000     1280.00000
    247.50000      185.40000       90.90000      566.50000      277.75000
    208.06000       81.00000      756.25000      424.36000      102.01000
   5098.50000     2499.75000     1872.54000     5721.65000     2227.50000
   1668.60000      818.10000     6806.25000    15578.75000     7638.12500
   3819.24000    11669.90000     4286.03600      918.09000     2805.27500
   2101.40600     1030.30100        7.83240        2.49181       10.32421

24
      8.90000       27.50000       20.50000       60.10000        1.80000
      4.70000        2.50000      560.00000       21.00000        0.00000
    244.75000      182.45000      534.89000      563.75000     1652.75000
   1232.05000       79.21000      756.25000      420.25000     3612.01000
   5017.37500    14709.47500    10965.24500    33881.37500     2178.27500
   1623.80500     4760.52100     6730.62500    15503.12500    45450.62500
   3740.22500    11556.87500    25257.02500    32146.88900    99330.27500
  74046.20500   217081.80100        3.21000         .21182        3.42182

25
      5.30000       40.00000       20.70000       10.10000       38.20000
      3.50000        2.50000     8740.00000      588.00000      210.00000
    212.00000      109.71000       53.53000      828.00000      404.00000
    209.07000       28.09000     1600.00000      428.49000      102.01000
   4388.40000     2141.20000     1108.07100     8362.80000     1123.60000
    581.46300      283.70900     8480.00000    33120.00000    16160.00000
   2270.99700    17139.60000     4327.74900      540.65300     4080.40000
   2111.60700     1030.30100        3.21000        1.44978        4.65978

26
      5.00000       15.00000       24.40000       35.20000        3.80000
      3.50000        2.90000     2030.00000      140.00000      170.00000
     75.00000      122.00000      176.00000      366.00000      528.00000
    850.88000       25.00000      225.00000      595.36000     1239.04000
   1830.00000     2640.00000     4294.40000    12883.20000      375.00000
    610.00000      880.00000     1125.00000     5490.00000     7920.00000
   2976.80000     8930.40000    20956.67200     6195.20000    18585.60000
  30232.57600    43614.20800        3.72360         .45113        4.17473
```


BEST COPY AVAILABLE

Table B-2. — Phase IIa (effluent) transformed variable listing and data matrix. -- Continued

```
27
        4.80000        27.50000        16.20000        59.90000         4.80000
        2.40000         2.00000      1050.00000        91.00000       130.00000
      132.00000        77.76000       287.52000       445.50000      1647.25000
      970.38000        23.04000       756.25000       262.44000      3588.01000
     2138.40000      7906.80000      4657.82400     26685.45000       633.60000
      373.24800      1380.09600      3630.00000     12251.25000     45299.37500
     1259.71200      7217.10000     15720.15600     17222.44800     98670.27500
    58125.76200    214921.79900         2.56800          .91484         3.48284

28
        5.00000        15.00000        16.00000        35.20000        23.60000
        3.20000         3.60000      5780.00000      1500.00000      1190.00000
       75.00000        80.00000       176.00000       240.00000       528.00000
      563.20000        25.00000       225.00000       256.00000      1239.04000
     1200.00000      2640.00000      2816.00000      8448.00000       375.00000
      400.00000       880.00000      1125.00000      3600.00000      7920.00000
     1280.00000      3840.00000      9011.20000      6195.20000     18585.60000
    19824.64000     43614.20800         4.62240         4.83358         9.45598

29
        4.80000        27.50000        20.60000        35.00000         4.80000
        2.00000         2.40000      1010.00000        56.00000        40.00000
      132.00000        98.88000       168.00000       566.50000       962.50000
      721.00000        23.04000       756.25000       424.36000      1225.00000
     2719.20000      4620.00000      3460.80000     19827.50000       633.60000
      474.62400       806.40000      3630.00000     15578.75000     26468.75000
     2036.92800     11669.90000     14852.60000      5880.00000     33687.50000
    25235.00000     42875.00000         3.08160          .32895         3.41055

30
        5.30000        40.00000        24.30000        35.30000         3.10000
        3.80000         3.00000       371.00000        21.00000        40.00000
      212.00000       128.79000       187.09000       972.00000      1412.00000
      857.79000        28.09000      1600.00000       590.49000      1246.09000
     5151.60000      7483.60000      4546.28700     34311.60000      1123.60000
      682.58700       991.57700      8480.00000     38880.00000     56480.00000
     3129.59700     23619.60000     20844.29700      6604.27700     49843.60000
    30279.98700     43986.97700         3.85200          .18097         4.03297
```


BEST COPY AVAILABLE

Table B-3. — Phase IIa effluent brine regression results.

```
**********************************************************************************
STEP NUMBER 7
VARIABLE'X2^2*X4' ADDED
R-SQUARED =  .80343666815

                                    AOV

SOURCE              DF      SUM OF SQUARES         MEAN SQUARE          F-VALUE
TOTAL               29           566.03636
REGRESSION           7           454.77437            64.96777            12.85
RESIDUAL            22           111.26199             5.05736

STANDARD ERROR =  2.24885822767

                 F TO   PART          F TO        REGRESSION COEFFICIENTS          STD
#--VARIABLE     ENTER   CORR    TOL DELETE  STD.FORMAT              E-FORMAT       ERROR
 1.CATL CONC      .24   .106   .998
 2.RESID TIME                          26.06     -3.96436 -.396436177624E+01       .7766
 3.FEED TEMP      .06   .053   .952
 4.AIR MASSFL                          39.30     -2.72907 -.272906688824E+01       .4353
11.X1*X2          .16   .088   .740
12.X1*X3          .29   .117   .994
13.X1*X4          .51   .154   .614
14.X2*X3          .10   .070   .134
15.X2*X4                              22.65      .10980  .109798640743E+00       .0231
16.X3*X4          .01   .022   .093
17.X1^2           .28   .115   .994
18.X2^2                               10.88      .04457  .445707022557E-01       .0135
19.X3^2           .12   .076   .957
20.X4^2                               19.72      .02162  .216178911310E-01       .0049
21.X1*X2*X3       .22   .103   .726
22.X1*X2*X4       .42   .141   .529
23.X1*X3*X4       .52   .155   .636
24.X2*X3*X4       .03   .041   .059
25.X1^2*X2        .18   .092   .889
26.X1^2*X3        .27   .113   .992
27.X1^2*X4        .54   .159   .823
28.X2^2*X1        .23   .103   .485
29.X2^2*X3        .15   .083   .051
30.X2^2*X4                             5.38     -.00082 -.817384238525E-03       .0004
31.X3^2*X1        .37   .131   .989
32.X3^2*X2        .17   .090   .348
33.X3^2*X4        .04   .043   .281
34.X4^2*X1        .16   .088   .397
35.X4^2*X2                            14.70     -.00065 -.651536910553E-03       .0002
36.X4^2*X3        .01   .025   .039
Variable'X4^3'does not exceed tolerance.

Constant =  84.8795421544
```


BEST COPY AVAILABLE

Table B-3. — Phase IIa effluent brine regression results. — Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	4.62240	5.64249	-1.02009	-.45361	
2	3.08160	2.62133	.46027	.20467	
3	2.05440	4.61485	-2.56045	-1.13855	
4	3.59520	2.58827	1.00693	.44775	
5	1.02720	3.22337	-2.19617	-.97657	
6	3.08160	6.63340	-3.55180	-1.57938	
7	3.21000	4.60640	-1.39640	-.62094	
8	26.32200	23.86423	2.45777	1.09290	
9	3.33840	2.60127	.73713	.32778	
10	2.56800	5.55560	-2.98760	-1.32849	
11	2.69640	4.60640	-1.91000	-.84932	
12	4.23720	2.61457	1.62263	.72153	
13	6.80520	6.63340	.17180	.07639	
14	5.77800	2.62133	3.15667	1.40368	
15	1.15560	3.25861	-2.10301	-.93514	
16	7.44720	5.59893	1.84827	.82187	
17	6.29160	4.60640	1.68520	.74936	
18	5.39280	2.61457	2.77823	1.23539	
19	5.39280	2.90726	2.48554	1.10524	
20	3.85200	6.60814	-2.75614	-1.22557	
21	4.62240	2.15556	2.46684	1.09693	
22	2.31120	2.62133	-.31013	-.13791	
23	7.83240	6.63340	1.19900	.53316	
24	3.21000	3.23504	-.02504	-.01114	
25	3.21000	.75105	2.45895	1.09342	
26	3.72360	5.55560	-1.83200	-.81463	
27	2.56800	3.21178	-.64378	-.28627	
28	4.62240	5.55560	-.93320	-.41496	
29	3.08160	2.62817	.45343	.20163	
30	3.85200	4.61485	-.76285	-.33921	

BEST COPY AVAILABLE

Table B-4. — Phase IIa effluent gas regression results.

```
********************************************************************************
STEP NUMBER 8
VARIABLE 'X1^2*X4' ADDED
R-SQUARED =  .92523794466

                                    AOV

SOURCE              DF      SUM OF SQUARES         MEAN SQUARE         F-VALUE
TOTAL               29           100.98336
REGRESSION           8            93.43364            11.67920           32.49
RESIDUAL            21             7.54972              .35951

STANDARD ERROR =  .599592070316

                 F TO   PART          F TO        REGRESSION COEFFICIENTS        STD
#--VARIABLE     ENTER   CORR    TOL  DELETE  STD.FORMAT            E-FORMAT      ERROR
 1.CATL CONC      .00   .006  .196
 2.RESID TIME                       44.32      -.42466 -.424664570359E+00       .0638
 3.FEED TEMP      .37   .135  .005
 4.AIR MASSFL    1.65   .276  .288
11.X1*X2          .00   .011  .161
12.X1*X3          .00   .005  .178
13.X1*X4                           58.70      -.07614 -.761442871999E-01       .0099
14.X2*X3          .01   .022  .006
15.X2*X4         1.47   .262  .213
16.X3*X4         1.43   .259  .257
17.X1^2           .18   .095  .126
18.X2^2           .04   .047  .007
19.X3^2                            45.92      -.01498 -.149766454711E-01       .0022
20.X4^2          2.05   .305  .190
21.X1*X2*X3       .00   .009  .149
22.X1*X2*X4                        19.37       .00056  .560858835953E-03       .0001
23.X1*X3*X4                        10.63       .00134  .133571508365E-02       .0004
24.X2*X3*X4      1.33   .250  .190
25.X1^2*X2        .02   .034  .137
26.X1^2*X3        .28   .117  .123
27.X1^2*X4                         17.67       .00137  .137393164227E-02       .0003
28.X2^2*X1        .01   .027  .122
29.X2^2*X3                         17.14       .00022  .215962338448E-03       .0001
30.X2^2*X4        .60   .170  .152
31.X3^2*X1        .01   .023  .151
32.X3^2*X2        .26   .114  .017
33.X3^2*X4       1.41   .257  .207
34.X4^2*X1                         22.29       .00024  .240259819476E-03       .0001
35.X4^2*X2       1.31   .248  .196
36.X4^2*X3       1.70   .280  .180
37.X4^3          1.86   .292  .163

Constant =  18.5551349682
```


BEST COPY AVAILABLE

Table B-4. — Phase IIa effluent gas regression results.—Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	2.69142	3.90412	-1.21270	-2.02254	**
2	.98967	.93262	.05705	.09515	
3	.60322	.06961	.53361	.88996	
4	5.18616	4.84172	.34444	.57445	
5	3.80644	3.23363	.57281	.95534	
6	3.27156	3.96093	-.68937	-1.14974	
7	1.07965	.50507	.57457	.95827	
8	6.21334	5.73780	.47554	.79311	
9	.41589	.87464	-.45875	-.76510	
10	.65414	.60403	.05012	.08358	
11	.17994	.61841	-.43847	-.73128	
12	.12406	-.32372	.44779	.74682	
13	3.49192	3.90774	-.41582	-.69351	
14	.41236	.82737	-.41500	-.69214	
15	.21253	-.06210	.27463	.45803	
16	6.04087	5.96955	.07132	.11895	
17	1.43953	1.77830	-.33878	-.56501	
18	1.98499	1.46582	.51917	.86588	
19	.30810	.83839	-.53028	-.88441	
20	.59916	1.10102	-.50186	-.83700	
21	.96443	1.09126	-.12684	-.21154	
22	.24742	-.04594	.29336	.48926	
23	2.49181	2.21206	.27975	.46657	
24	.21182	.36282	-.15099	-.25183	
25	1.44978	1.42855	.02123	.03541	
26	.45113	.96719	-.51606	-.86068	
27	.91484	.38934	.52550	.87643	
28	4.83358	3.66677	1.16680	1.94599	
29	.32895	.82803	-.49908	-.83236	
30	.18097	.09466	.08630	.14394	

BEST COPY AVAILABLE

Table B-5. – Phase IIa (interstage) transformed variable listing and data matrix.

```
+-----------------------------------------+-----------------------------------------+
*                    BASIC STATISTICS AND DATA MANIPULATION                         *
+-----------------------------------------+-----------------------------------------+
                              PARADOX PHASE IIa

Data file name: PVPH2a:H8
Number of observations: 30
Number of variables: 40


Variables names:
   1. CATL CONC
   2. RESID TIME
   3. FEED TEMP
   4. AIR MASSFL
   5. I FILT S-2
   6. E UNFL S-2
   7. E FILT S-2
   8. I H2S GAST
   9. E H2S GAST
  10. E H2S TITR
  11. X1*X2
  12. X1*X3
  13. X1*X4
  14. X2*X3
  15. X2*X4
  16. X3*X4
  17. X1^2
  18. X2^2
  19. X3^2
  20. X4^2
  21. X1*X2*X3
  22. X1*X2*X4
  23. X1*X3*X4
  24. X2*X3*X4
  25. X1^2*X2
  26. X1^2*X3
  27. X1^2*X4
  28. X2^2*X1
  29. X2^2*X3
  30. X2^2*X4
  31. X3^2*X1
  32. X3^2*X2
  33. X3^2*X4
  34. X4^2*X1
  35. X4^2*X2
  36. X4^2*X3
  37. X4^3
  38. % REM I-S
  39. % REM GAS
  40. TOTL % REM

                                Subfiles:  NONE

                              PARADOX PHASE IIa

      Variable # 1   Variable # 2   Variable # 3   Variable # 4   Variable # 5
         Variable # 6   Variable # 7   Variable # 8   Variable # 9   Variable #10
      Variable #11   Variable #12   Variable #13   Variable #14   Variable #15
         Variable #16   Variable #17   Variable #18   Variable #19   Variable #20
      Variable #21   Variable #22   Variable #23   Variable #24   Variable #25
         Variable #26   Variable #27   Variable #28   Variable #29   Variable #30
      Variable #31   Variable #32   Variable #33   Variable #34   Variable #35
         Variable #36   Variable #37   Variable #38   Variable #39   Variable #40
OBS#
   1
          5.00000       15.00000       14.00000       35.00000       11.20000
             6.00000        3.60000     4030.00000      840.00000      810.00000
           75.00000       74.00000      175.00000      222.00000      525.00000
            518.00000       25.00000      225.00000      219.04000     1225.00000
         1110.00000     2625.00000     2590.00000     7770.00000      375.00000
            370.00000      875.00000     1125.00000     3330.00000     7875.00000
         1095.20000     3285.60000     7666.40000     6125.00000    18375.00000
           18130.00000    42875.00000       14.38080       12.91242       27.29322
   2
          4.90000       27.50000       19.90000       35.10000        3.60000
             2.40000        2.40000     1260.00000      168.00000       90.00000
          134.73000       97.51000      171.99000      547.25000      965.25000
            698.49000       24.01000      756.25000      396.01000     1232.01000
         2681.52500     4729.72500     3422.60100    19208.47500      660.27500
            477.79900      842.75100     3705.62500    15049.37500     26544.37500
         1940.44900    10890.27500    13899.95100     6036.84900    33880.27500
           24516.99900    43243.55100        4.62240        7.42256       12.04496
```


BEST COPY AVAILABLE!

Table B-5. — Phase IIa (interstage) transformed variable listing and data matrix. — Continued

3

5.10000	40.00000	24.40000	35.30000	.80000
.40000	1.60000	420.00000	70.00000	40.00000
204.00000	124.44000	180.03000	976.00000	1412.00000
861.32000	26.01000	1600.00000	595.36000	1246.09000
4977.60000	7201.20000	4392.73200	34452.80000	1040.40000
624.64400	918.15300	8160.00000	39040.00000	56480.00000
3036.33600	23814.40000	21016.20800	6355.05900	49843.60000
30404.59600	43986.97700	1.02720	3.61932	4.64652

4

.90000	27.50000	15.50000	35.60000	4.80000
1.60000	2.80000	3370.00000	869.00000	470.00000
24.75000	13.95000	32.04000	426.25000	979.00000
551.80000	.81000	756.25000	240.25000	1267.36000
383.62500	881.10000	496.62000	15174.50000	22.27500
12.55500	28.83600	680.62500	11721.87500	26922.50000
216.22500	6606.87500	8552.90000	1140.62400	34852.40000
19644.08000	45118.01600	6.16320	20.13520	26.29840

5

.90000	27.50000	19.80000	60.00000	5.60000
1.60000	.80000	1820.00000	378.00000	300.00000
24.75000	17.82000	54.00000	544.50000	1650.00000
1188.00000	.81000	756.25000	392.04000	3600.00000
490.05000	1485.00000	1069.20000	32670.00000	22.27500
16.03800	48.60000	680.62500	14973.75000	45375.00000
352.83600	10781.10000	23522.40000	3240.00000	99000.00000
71280.00000	216000.00000	7.19040	18.32731	25.51771

6

.90000	27.50000	19.80000	10.10000	22.80000
3.20000	2.40000	6720.00000	1930.00000	940.00000
24.75000	17.82000	9.09000	544.50000	277.75000
199.98000	.81000	756.25000	392.04000	102.01000
490.05000	249.97500	179.98200	5499.45000	22.27500
16.03800	8.10100	680.62500	14973.75000	7638.12500
352.83600	10781.10000	3959.60400	91.80900	2805.27500
2019.79800	1030.30100	29.27520	11.39113	40.66623

7

4.60000	40.00000	17.30000	35.10000	2.60000
3.90000	2.50000	994.00000	126.00000	40.00000
184.00000	79.58000	161.46000	692.00000	1404.00000
607.23000	21.16000	1600.00000	299.29000	1232.01000
3183.20000	6458.40000	2792.25800	24289.20000	846.40000
366.06800	742.71600	7360.00000	27680.00000	56160.00000
1376.73400	11971.60000	10505.07900	5667.24600	49280.40000
21313.77300	43243.55100	3.33840	8.51720	11.85560

8

4.70000	15.00000	19.80000	10.10000	34.20000
18.30000	20.50000	13700.00000	6720.00000	4640.00000
70.50000	93.06000	47.47000	297.00000	151.50000
199.98000	22.09000	225.00000	392.04000	102.01000
1395.90000	712.05000	939.90600	2999.70000	381.35000
437.38200	223.10900	1057.50000	4455.00000	2272.50000
1842.58800	5880.60000	3959.60400	479.44700	1530.15000
2019.79800	1030.30100	43.91280	12.66708	56.57988

BEST COPY AVAILABLE

Table B-5. — Phase IIa (interstage) transformed variable listing and data matrix. -- Continued

9

5.00000	27.50000	19.90000	35.40000	2.70000
3.40000	2.60000	1410.00000	70.00000	130.00000
137.50000	99.50000	177.00000	547.25000	973.50000
704.46000	25.00000	756.25000	396.01000	1252.16000
2736.25000	4867.50000	3522.30000	19372.65000	687.50000
497.50000	885.00000	3781.25000	15049.37500	26771.25000
1980.05000	10890.27500	14018.75400	6265.80000	34461.90000
24937.88400	44361.86400	3.46680	8.37719	11.84399

10

9.10000	15.00000	21.00000	35.20000	1.20000
4.40000	2.00000	2050.00000	203.00000	130.00000
136.50000	191.10000	320.32000	315.00000	528.00000
739.20000	82.81000	225.00000	441.00000	1239.04000
2866.50000	4804.80000	6726.72000	11088.00000	1242.15000
1739.01000	2914.91200	2047.50000	4725.00000	7920.00000
4013.10000	6615.00000	15523.20000	11275.26400	18585.60000
26019.84000	43614.20800	1.54080	6.60589	8.14669

11

9.30000	40.00000	20.10000	35.10000	2.60000
1.10000	2.10000	399.00000	21.00000	85.00000
372.00000	186.93000	326.43000	804.00000	1404.00000
705.51000	86.49000	1600.00000	404.01000	1232.01000
7477.20000	13057.20000	6561.24300	28220.40000	3459.60000
1738.44900	3035.79900	14880.00000	32160.00000	56160.00000
3757.29300	16160.40000	14180.75100	11457.69300	49280.40000
24763.40100	43243.55100	3.33840	3.41888	6.75728

12

9.10000	27.50000	24.20000	35.20000	2.60000
5.10000	3.30000	560.00000	21.00000	0.00000
250.25000	220.22000	320.32000	605.50000	968.00000
851.84000	82.81000	756.25000	585.64000	1239.04000
6056.05000	8808.80000	7751.74400	23425.60000	2277.27500
2004.00200	2914.91200	6881.87500	18301.25000	26620.00000
5329.32400	16105.10000	20614.52900	11275.26400	34073.60000
29984.76800	43614.20800	3.33840	3.30831	6.64671

13

5.10000	27.50000	16.80000	10.10000	34.20000
5.10000	5.30000	9800.00000	2060.00000	1280.00000
140.25000	85.68000	51.51000	462.00000	277.75000
169.68000	26.01000	756.25000	282.24000	102.01000
2356.20000	1416.52500	865.36800	4666.20000	715.27500
436.96800	262.70100	3856.87500	12705.00000	7638.12500
1439.42400	7761.60000	2850.62400	520.25100	2805.27500
1713.76800	1030.30100	43.91280	16.61206	60.52486

14

4.90000	27.50000	20.40000	35.10000	5.00000
5.50000	4.50000	1630.00000	70.00000	85.00000
134.75000	99.96000	171.99000	561.00000	965.25000
716.04000	24.01000	756.25000	416.16000	1232.01000
2748.90000	4729.72500	3508.59600	19691.10000	660.27500
489.80400	842.75100	3705.62500	15427.50000	26544.37500
2039.18400	11444.40000	14607.21600	6036.84900	33880.27500
25133.00400	43243.55100	6.42000	9.60220	16.02220

BEST COPY AVAILABLE

Table B-5. — Phase IIa (interstage) transformed variable listing and data matrix. — Continued

15

4.90000	27.50000	24.20000	60.30000	2.60000
2.70000	.90000	588.00000	21.00000	43.00000
134.75000	110.58000	295.47000	665.50000	1658.25000
1459.26000	24.01000	756.25000	585.64000	3636.09000
3260.95000	8125.42500	7150.37400	40129.65000	660.27500
581.04200	1447.80300	3705.62500	18301.25000	45601.87500
2869.63600	16105.10000	35314.09200	17816.84100	99992.47500
87993.37800	219256.22700	3.33840	5.95074	9.28914

16

1.00000	15.00000	20.20000	35.10000	21.90000
4.20000	5.80000	5210.00000	1880.00000	1410.00000
15.00000	20.20000	35.10000	303.00000	526.50000
709.02000	1.00000	225.00000	408.04000	1232.01000
303.00000	526.50000	709.02000	10635.30000	15.00000
20.20000	35.10000	225.00000	4545.00000	7897.50000
408.04000	6120.60000	14322.20400	1232.01000	18480.15000
24886.60200	43243.55100	28.11960	16.74093	44.86053

17

1.00000	40.00000	20.50000	35.10000	10.20000
5.10000	4.90000	1880.00000	168.00000	130.00000
40.00000	20.50000	35.10000	820.00000	1404.00000
719.55000	1.00000	1600.00000	420.25000	1232.01000
820.00000	1404.00000	719.55000	28782.00000	40.00000
20.50000	35.10000	1600.00000	32800.00000	56160.00000
420.25000	16810.00000	14750.77500	1232.01000	49280.40000
25256.20500	43243.55100	13.09680	16.10899	29.20579

18

.90000	27.50000	24.20000	35.20000	11.90000
4.20000	4.20000	2460.00000	336.00000	260.00000
24.75000	21.78000	31.68000	665.50000	968.00000
851.84000	.81000	756.25000	585.64000	1239.04000
598.95000	871.20000	766.65600	23425.60000	22.27500
19.60200	28.51200	680.62500	18301.25000	26620.00000
527.07600	16105.10000	20614.52800	1115.13600	34073.60000
29984.76800	43614.20800	15.27960	14.53295	29.81255

19

4.60000	40.00000	20.70000	60.10000	4.70000
4.60000	4.20000	410.00000	21.00000	130.00000
184.00000	95.22000	276.46000	828.00000	2404.00000
1244.07000	21.16000	1600.00000	428.49000	3612.01000
3808.80000	11058.40000	5722.72200	49762.80000	846.40000
438.01200	1271.71600	7360.00000	33120.00000	96160.00000
1971.05400	17139.60000	25752.24900	16615.24600	144480.40000
74768.60700	217081.80100	6.03480	6.01536	12.05016

20

4.50000	27.50000	24.30000	10.20000	20.80000
4.60000	3.00000	6840.00000	350.00000	260.00000
123.75000	109.35000	45.90000	668.25000	280.50000
247.86000	20.25000	756.25000	590.49000	104.04000
3007.12500	1262.25000	1115.37000	6816.15000	556.87500
492.07500	206.55000	3403.12500	18376.87500	7713.75000
2657.20500	16238.47500	6022.99800	468.18000	2861.10000
2528.17200	1061.20800	26.70720	11.70934	38.41654

BEST COPY AVAILABLE

Table B-5. — Phase IIa (interstage) transformed variable listing and data matrix. — Continued

21

5.10000	15.00000	20.50000	60.20000	8.00000
4.00000	3.60000	1740.00000	175.00000	260.00000
76.50000	104.55000	307.02000	307.50000	903.00000
1234.10000	26.01000	225.00000	420.25000	3624.04000
1568.25000	4605.30000	6293.91000	18511.50000	390.15000
533.20500	1565.80200	1147.50000	4612.50000	13545.00000
2143.27500	6303.75000	25299.05000	18482.60400	54360.60000
74292.82000	218167.20800	10.27200	9.58916	19.86116

22

8.70000	27.50000	17.20000	35.10000	3.10000
3.00000	1.80000	1090.00000	42.00000	170.00000
239.25000	149.64000	305.37000	473.00000	965.25000
603.72000	75.69000	756.25000	295.84000	1232.01000
4115.10000	8397.67500	5252.36400	16602.30000	2081.47500
1301.86800	2656.71900	6579.37500	13007.50000	26544.37500
2573.80800	8135.60000	10383.98400	10718.48700	33880.27500
21190.57200	43243.55100	3.98040	6.42110	10.40150

23

9.00000	27.50000	20.60000	10.10000	37.10000
6.60000	6.10000	11000.00000	1470.00000	1280.00000
247.50000	185.40000	90.90000	566.50000	277.75000
208.06000	81.00000	756.25000	424.36000	102.01000
5098.50000	2499.75000	1872.54000	5721.65000	2227.50000
1668.60000	818.10000	6806.25000	15578.75000	7638.12500
3819.24000	11669.90000	4286.03600	918.09000	2805.27500
2101.40600	1030.30100	47.63640	18.64619	66.28259

24

8.90000	27.50000	20.50000	60.10000	1.80000
4.70000	2.50000	560.00000	21.00000	0.00000
244.75000	182.45000	534.89000	563.75000	1652.75000
1232.05000	79.21000	756.25000	420.25000	3612.01000
5017.37500	14709.47500	10965.24500	33881.37500	2178.27500
1623.80500	4760.52100	6730.62500	15503.12500	45450.62500
3740.22500	11556.87500	25257.02500	32146.88900	99330.27500
74046.20500	217081.80100	2.31120	5.64857	7.95977

25

5.30000	40.00000	20.70000	10.10000	38.20000
3.50000	2.50000	8740.00000	588.00000	210.00000
212.00000	109.71000	53.53000	828.00000	404.00000
209.07000	28.09000	1600.00000	428.49000	102.01000
4388.40000	2141.20000	1108.07100	8362.80000	1123.60000
581.46300	283.70900	8480.00000	33120.00000	16160.00000
2270.99700	17139.60000	4327.74900	540.65300	4080.40000
2111.60700	1030.30100	49.04880	21.54945	70.59825

26

5.00000	15.00000	24.40000	35.20000	3.80000
3.50000	2.90000	2030.00000	140.00000	170.00000
75.00000	122.00000	176.00000	366.00000	528.00000
858.88000	25.00000	225.00000	595.36000	1239.04000
1830.00000	2640.00000	4294.40000	12883.20000	375.00000
610.00000	880.00000	1125.00000	5490.00000	7920.00000
2976.80000	8930.40000	20956.67200	6195.20000	18585.60000
30232.57600	43614.20800	4.87920	6.54144	11.42064

BEST COPY AVAILABLE

Table B-5. — Phase IIa (interstage) transformed variable listing and data matrix. — Continued

```
27
        4.80000        27.50000        16.20000        59.90000         4.80000
        2.40000         2.00000      1050.00000        91.00000       130.00000
      132.00000        77.76000       287.52000       445.50000      1647.25000
      970.38000        23.04000       756.25000       262.44000      3588.01000
     2138.40000      7906.80000      4657.82400     26685.45000       633.60000
      373.24800      1380.09600      3630.00000     12251.25000     45299.37500
     1259.71200      7217.10000     15720.15600     17222.44800     98670.27500
    58125.76200    214921.79900         6.16320        10.55583        16.71903

28
        5.00000        15.00000        16.00000        35.20000        23.60000
        3.20000         3.60000      5780.00000      1500.00000      1190.00000
       75.00000        80.00000       176.00000       240.00000       528.00000
      563.20000        25.00000       225.00000       256.00000      1239.04000
     1200.00000      2640.00000      2816.00000      8448.00000       375.00000
      400.00000       880.00000      1125.00000      3600.00000      7920.00000
     1280.00000      3840.00000      9011.20000      6195.20000     18585.60000
    19824.64000     43614.20800        30.30240        18.62538        48.92778

29
        4.80000        27.50000        20.60000        35.00000         4.80000
        2.00000         2.40000      1010.00000        56.00000        40.00000
      132.00000        98.88000       168.00000       566.50000       962.50000
      721.00000        23.04000       756.25000       424.36000      1225.00000
     2719.20000      4620.00000      3460.80000     19827.50000       633.60000
      474.62400       806.40000      3630.00000     15578.75000     26468.75000
     2036.92800     11669.90000     14852.60000      5880.00000     33687.50000
    25235.00000     42875.00000         6.16320         5.93288        12.09606

30
        5.30000        40.00000        24.30000        35.30000         3.10000
        3.80000         3.00000       371.00000        21.00000        40.00000
      212.00000       128.79000       187.09000       972.00000      1412.00000
      857.79000        28.09000      1600.00000       590.49000      1246.09000
     5151.60000      7483.60000      4546.28700     34311.60000      1123.60000
      682.58700       991.57700      8480.00000     38880.00000     56480.00000
     3129.59700     23619.60000     20844.29700      6604.27700     49843.60000
    30279.98700     43986.97700         3.98040         3.19707         7.17747
```


BEST COPY AVAILABLE

Table B-6. — Phase IIa interstage brine regression results.

```
********************************************************************************
STEP NUMBER 6
VARIABLE 'X1*X2*X4' ADDED
R-SQUARED =  .80498779278

                                    AOV

SOURCE              DF      SUM OF SQUARES         MEAN SQUARE         F-VALUE
TOTAL               29          6772.17381
REGRESSION           4          5451.51725          1362.87931           25.80
RESIDUAL            25          1320.65656            52.82626

STANDARD ERROR =  7.2681677534

                 F TO   PART          F TO        REGRESSION COEFFICIENTS        STD
#--VARIABLE     ENTER   CORR    TOL DELETE  STD.FORMAT              E-FORMAT     ERROR
 1.CATL CONC      .55   .150   .389
 2.RESID TIME     .44   .134   .771
 3.FEED TEMP      .27   .105   .112
 4.AIR MASSFL                    8.79       -.86345 -.863452749374E+00     .2912
11.X1*X2         1.54   .245   .135
12.X1*X3          .22   .095   .367
13.X1*X4          .00   .008   .183
14.X2*X3          .27   .105   .610
15.X2*X4          .60   .156   .266
16.X3*X4                       16.32       -.06391 -.639094797339E-01     .0158
17.X1^2           .49   .142   .438
18.X2^2           .10   .064   .772
19.X3^2           .38   .124   .118
20.X4^2           .04   .038   .003
21.X1*X2*X3      1.06   .206   .140
22.X1*X2*X4                     4.80       -.00093 -.931719001837E-03     .0004
23.X1*X3*X4       .03   .033   .176
24.X2*X3*X4       .32   .115   .244
25.X1^2*X2       1.71   .258   .229
26.X1^2*X3        .35   .119   .439
27.X1^2*X4        .01   .020   .293
28.X2^2*X1        .99   .199   .227
29.X2^2*X3        .03   .035   .700
30.X2^2*X4        .24   .100   .501
31.X3^2*X1        .04   .039   .344
32.X3^2*X2        .18   .086   .464
33.X3^2*X4        .04   .042   .002
34.X4^2*X1        .05   .045   .141
35.X4^2*X2        .27   .106   .144
36.X4^2*X3                     28.80        .00112  .112109207367E-02     .0002
37.X4^3           .04   .039   .007

Constant =  60.881754075
```


BEST COPY AVAILABLE

Table B-6. — Phase IIa interstage brine regression results. — Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	14.38080	15.43543	-1.05463	-.14510	
2	4.62240	9.01347	-4.39107	-.60415	
3	1.02720	2.73222	-1.70502	-.23459	
4	6.16320	16.07947	-9.91627	-1.36434	
5	7.19040	11.67797	-4.48757	-.61743	
6	29.27520	41.41174	-12.13654	-1.66982	
7	3.33840	9.64410	-6.30570	-.86758	
8	43.91280	40.98121	2.93159	.40335	
9	3.46680	8.71638	-5.24958	-.72227	
10	1.54080	7.94024	-6.39944	-.88048	
11	3.33840	1.08220	2.25620	.31042	
12	3.33840	1.45593	1.88247	.25900	
13	43.91280	41.91821	1.99459	.27443	
14	6.42000	8.58246	-2.16246	-.29752	
15	3.33840	6.63307	-3.29467	-.45330	
16	28.11960	12.67109	15.44851	2.12550	**
17	13.09680	11.59489	1.50191	.20664	
18	15.27960	8.85154	6.42806	.88441	
19	6.03480	2.99955	3.03525	.41761	
20	26.70720	37.89218	-11.18498	-1.53890	
21	10.27200	9.02946	1.24254	.17096	
22	3.98040	7.92344	-3.94304	-.54251	
23	47.63640	38.89068	8.74572	1.20329	
24	2.31120	-.44391	2.75511	.37907	
25	49.04880	39.17164	9.87716	1.35896	
26	4.87920	7.03141	-2.15221	-.29611	
27	6.16320	4.94187	1.22133	.16804	
28	30.30240	14.25991	16.04249	2.20723	**
29	6.16320	8.56839	-2.40519	-.33092	
30	3.98040	2.55500	1.42540	.19612	

BEST COPY AVAILABLE

Table B-7. — Phase IIa interstage gas regression results.

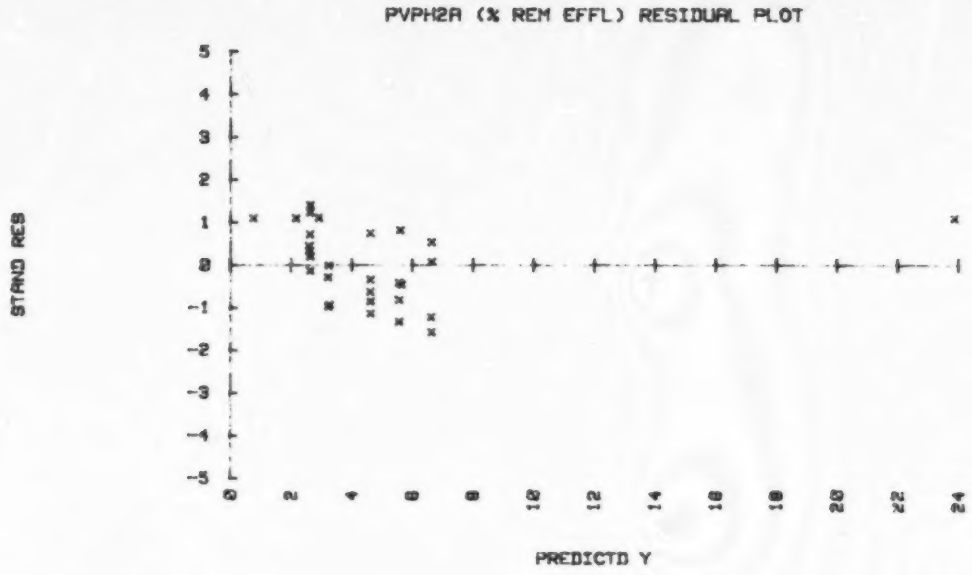
```
*******************************************************************************
STEP NUMBER 10
VARIABLE 'X4^2' ADDED
R-SQUARED =  .89499394571

                                    AOV

SOURCE              DF      SUM OF SQUARES         MEAN SQUARE         F-VALUE
TOTAL               29           899.06561
REGRESSION           8           804.65828           100.58228           22.37
RESIDUAL            21            94.40733             4.49559

STANDARD ERROR =  2.12027999316

                 F TO  PART          F TO        REGRESSION COEFFICIENTS        STD
#--VARIABLE     ENTER  CORR    TOL DELETE  STD.FORMAT            E-FORMAT      ERROR
 1.CATL CONC      .50  .156  .031
 2.RESID TIME     .04  .045  .184
 3.FEED TEMP                 38.93       -.93393 -.933929882800E+00     .1497
 4.AIR MASSFL                 5.56        .37717  .377173950432E+00     .1599
11.X1*X2          .40  .139  .014
12.X1*X3          .02  .032  .029
13.X1*X4                    19.33       -.11236 -.112362750365E+00     .0256
14.X2*X3          .01  .021  .139
15.X2*X4          .00  .006  .050
16.X3*X4          .01  .023  .011
17.X1^2           .47  .152  .009
18.X2^2           .06  .053  .169
19.X3^2           .23  .107  .006
20.X4^2                      2.59       -.00383 -.382810968142E-02     .0024
21.X1*X2*X3       .15  .085  .019
22.X1*X2*X4                 16.06       -.00227 -.227345902043E-02     .0006
23.X1*X3*X4       .46  .150  .010
24.X2*X3*X4       .05  .049  .056
25.X1^2*X2        .10  .070  .027
26.X1^2*X3                  16.32        .00741  .740954447155E-02     .0018
27.X1^2*X4        .74  .188  .033
28.X2^2*X1                   9.98        .00118  .117603792669E-02     .0004
29.X2^2*X3        .00  .000  .155
30.X2^2*X4        .10  .070  .113
31.X3^2*X1        .04  .043  .044
32.X3^2*X2        .10  .072  .115
33.X3^2*X4        .00  .005  .035
34.X4^2*X1                  18.10        .00182  .181831289645E-02     .0004
35.X4^2*X2       1.13  .231  .030
36.X4^2*X3        .03  .037  .012
Variable 'X4^3' does not exceed tolerance.

Constant =  29.5587981853
```


BEST COPY AVAILABLE

Table B-7. — Phase IIa interstage gas regression results. — Continued

OBS#	OBSERVED Y	PREDICTED Y	RESIDUAL	STAND.RES.	SIGNIF.
1	12.91242	13.81872	-.90630	-.42744	
2	7.42256	8.29313	-.87057	-.41059	
3	3.61932	4.56906	-.94974	-.44793	
4	20.13520	21.02292	-.88772	-.41868	
5	18.32731	17.28316	1.04415	.49246	
6	11.39113	13.98247	-2.59134	-1.22217	
7	9.51720	10.77221	-2.25501	-1.06354	
8	12.66708	12.88951	-.22243	-.10490	
9	8.37719	8.10038	.27682	.13056	
10	6.60589	7.35923	-.75334	-.35530	
11	3.41888	4.15999	-.74112	-.34954	
12	3.30831	2.91660	.39171	.18475	
13	16.61206	16.99905	-.38699	-.18252	
14	9.60220	7.91512	1.68708	.79569	
15	5.95074	5.16909	.78164	.36865	
16	16.74093	16.72950	.01142	.00539	
17	16.10899	16.07364	.03535	.01667	
18	14.53295	12.92410	1.60886	.75879	
19	6.01536	4.97563	1.03973	.49037	
20	11.70934	10.78563	.92371	.43565	
21	9.58916	13.18578	-3.59662	-1.69630	
22	6.42110	5.48716	.93394	.44048	
23	18.64619	19.87929	-1.23310	-.58157	
24	5.64857	4.11135	1.53722	.72501	
25	21.54945	18.02695	3.52250	1.66134	
26	6.54144	6.63415	-.09271	-.04373	
27	10.55583	11.35465	-.79882	-.37675	
28	18.62538	12.92316	5.70222	2.68937	**
29	5.93288	7.92862	-1.99574	-.94126	
30	3.19707	4.41187	-1.21480	-.57294	

BEST COPY AVAILABLE



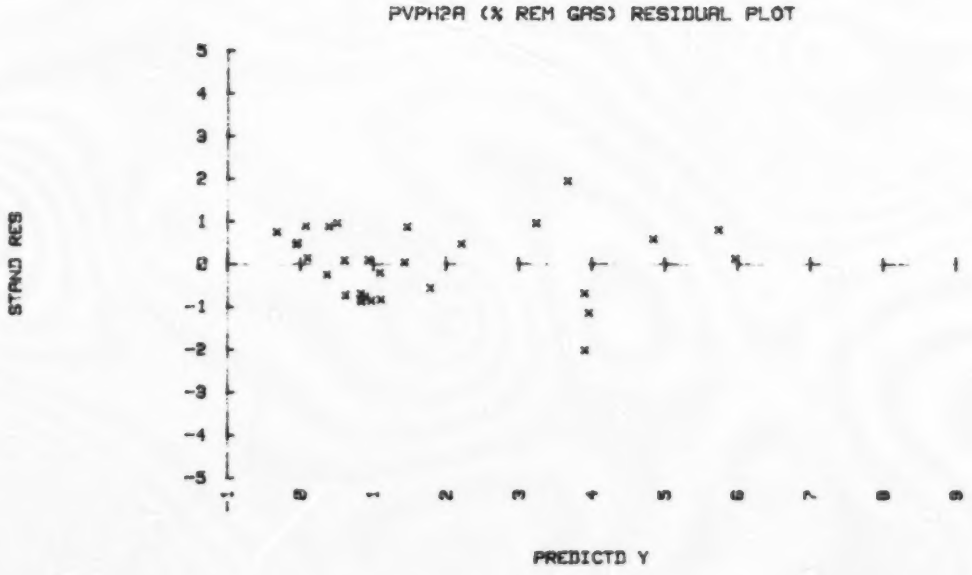
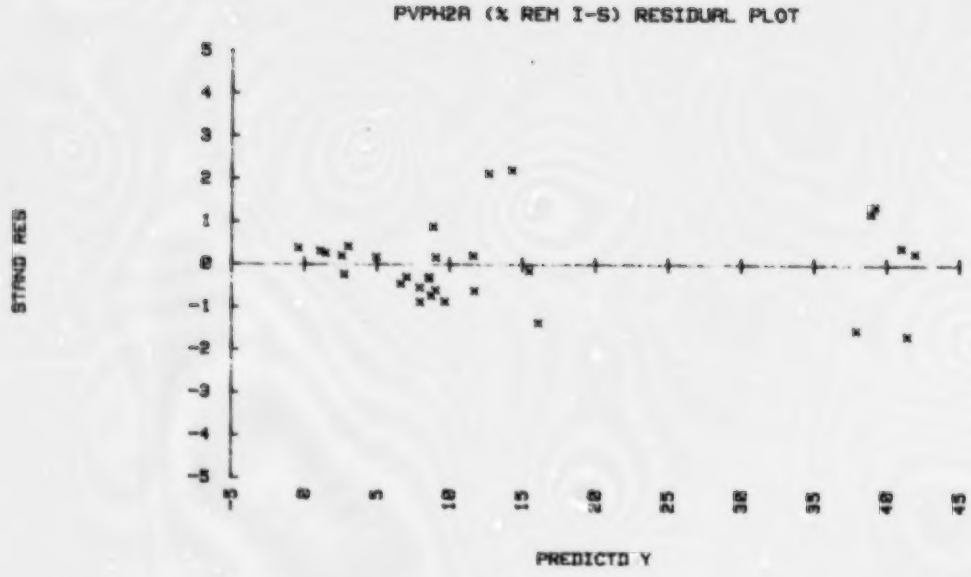


Figure B-1. – Phase IIa (effluent) standardized residual plots.

BEST COPY AVAILABLE



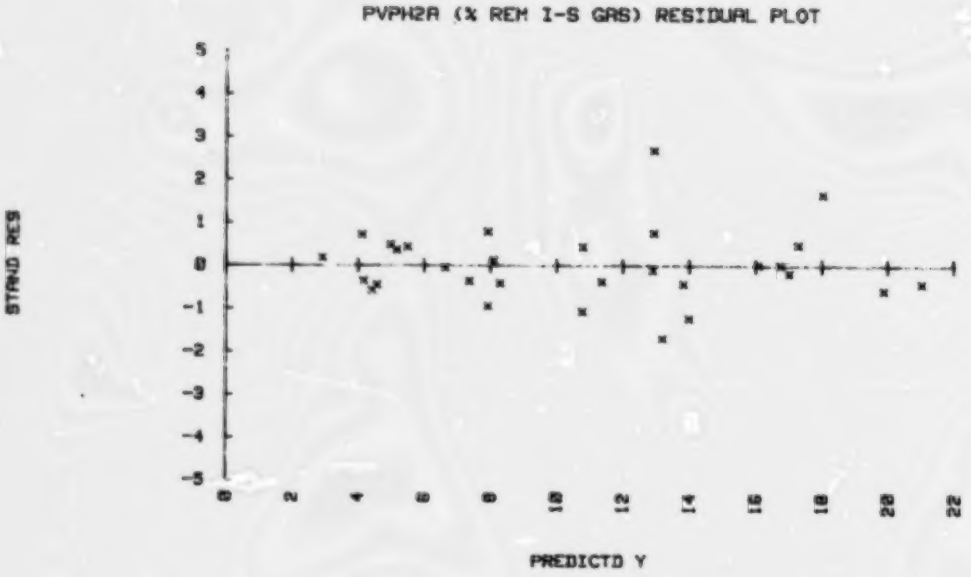


Figure B-2. – Phase IIa (interstage) standardized residual plots.

GPO 850-331

BEST COPY AVAILABLE

Mission of the Bureau of Reclamation

The Bureau of Reclamation of the U.S. Department of the Interior is responsible for the development and conservation of the Nation's water resources in the Western United States.

The Bureau's original purpose "to provide for the reclamation of arid and semiarid lands in the West" today covers a wide range of interrelated functions. These include providing municipal and industrial water supplies; hydroelectric power generation; irrigation water for agriculture; water quality improvement; flood control; river navigation; river regulation and control; fish and wildlife enhancement; outdoor recreation; and research on water-related design, construction, materials, atmospheric management, and wind and solar power.

Bureau programs most frequently are the result of close cooperation with the U.S. Congress, other Federal agencies, States, local governments, academic institutions, water-user organizations, and other concerned groups.

A free pamphlet is available from the Bureau entitled "Publications for Sale." It describes some of the technical publications currently available, their cost, and how to order them. The pamphlet can be obtained upon request from the Bureau of Reclamation, Attn D-822A, P O Box 25007, Denver Federal Center, Denver CO 80225-0007.

BEST COPY AVAILABLE